
Sincerely Yours,
Edward Weston.

# LECTURES ON ELECTRICAL APPARATUS AND EXPERIMENTS

ILLUSTRATED WITH CUTS
FROM LANTERN SLIDES

MONOGRAPH B-5

1915

ISSUED FOR

SCIENCE TEACHERS IN EDUCATIONAL INSTITUTIONS

"I myself have now for a long time ceased to look for anything more beautiful in this world, or more interesting, than the truth; or at least than the effort one is able to make towards the truth. I shall state nothing, therefore, that I have not verified myself, or that is not so fully accepted in the text-books as to render further verification superfluous. My facts shall be as accurate as though they appeared in a practical manual or scientific monograph, but I shall relate them in a somewhat livelier fashion than such works would allow, shall group them more harmoniously together, and blend them with freer and more mature reflections."—*From "The Life of the Bee," by Maurice Maeterlinck.*

WESTON ELECTRICAL INSTRUMENT CO.

NEWARK, NEW JERSEY

Mr 11. 1915.

# ARGUMENT

IN presenting Monograph "B-5" to our friends, the Science Teachers, it has been our belief that a Monograph which could, in substance, be used as the foundation for illustrated lectures or talks to students on electrical instruments and measurement apparatus would be acceptable.

In preceding Monographs, we have dealt principally with laboratory experiments, whereas in this Monograph we are attempting to render service to Science Teachers, in the class room, as well as the laboratory. A brief historical introduction is given, as this may help to promote interest in the subject.

We extend our thanks to the many teachers who have co-operated with us in preparing Monograph "B-5." Their encouragement has done much to strengthen our belief that lectures and exercises illustrated by cuts and by lantern slides will be acceptable in the teaching of physics in high schools.

We have discussed this Monograph with Mr. J. A. Randall, the Chairman of the Joint Committee on Physics, and while that gentleman heartily approves of the theme, it is his opinion that it may require further debate whether or not the information contained herein is presented in a manner that will appeal to Science Teachers.

We therefore invite the frank criticism of educators on this topic.

We also desire to express our indebtedness to Professor Albert F. Ganz for his painstaking and thorough revision of our copy.

WESTON ELECTRICAL INSTRUMENT CO.

# FOUNDATION FIRST

BY

## ALEX. C. HUMPHREYS, M.E., Sc.D., LL.D.

PRESIDENT OF THE STEVENS INSTITUTE OF TECHNOLOGY*

IT may seem to many of you, it certainly will to some of you, presumptuous on my part to give advice on teaching to professional teachers. First, I shall remind you that I am not appearing in this role on my own initiative. But, I shall try to be helpful in some small degree, at least, by drawing upon my experience as an employer of engineers, technically educated and otherwise. I shall make no effort to bring to your attention any novel proposition. It is my thought to remind you of things known but oft times forgotten or neglected.

I am firmly of the opinion that the fault in this country today is superficiality due to lack of thoroughness in fundamentals. Of course, I am not here referring only to the teachers of Science. I am rather referring to the teaching of all the subjects in the lower grades, and particularly to the three R's. You may resent my reference to such lowly subjects; but if we allow the youths of the country to slight the primary subjects, we are not only depriving them of tools continuingly needful, but we are training them to be careless, inexact, and lacking in a sense of responsibility.

Particularly with regard to the fundamentals, the boys and girls should not only be taught to understand but they should be **drilled in accurate and facile** performance.

I believe in interesting the learner by practical applications, but this understanding of the problem does not give facility in operation, that can only come from drill. The girl at the piano does not acquire facility in fingering by listening to explanations. She has to practice diligently and persistently to acquire the command of this part of the technique so that later no appreciable mental and physical effort will be required there-for while devoting herself to the music itself.

I hear young art students suggesting that they do not need, or intend to go through, the drudgery with which their predecessors burdened themselves. They are going to paint masterpieces by the exercise of untrammeled genius. It remains for them to discover that they must learn and drill to be artisans or else their art will have no adequate means of expression.

It has been my sad experience to come in contact with many people of native ability and good, though weak, intentions, who have failed to do effective work. I am sure that many of these cases of failure could be traced back, if we had all the records, to lack of fundamental training in the home and in the **primary school.** I have thought so much on this subject that I am tempted to think that the teachers who have the greatest opportunity and so carry the greatest responsibility are those in the lowest grades. And yet, these, to a great extent, learn to teach by experimenting on the young minds and hearts which come to them to be influenced probably for life. Perhaps a reform could be instituted by paying these teachers higher salaries than those of the upper classes.

Emphatically I do not think that high school work should be schemed as a preparation for college, whether it be for an arts course, or for a professional course. The schools should be organized and administered for the benefit of the masses; and this applies to the teaching of physics as well as to all other subjects.

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* Excerpts from an address at the winter meeting of the New Jersey Science Teachers' Association, December 5, 1914; held at Stevens Institute of Technology, Hoboken, N. J.

I am most decidedly of the opinion that physics should be taught in the high school with regard to the physical conception rather than of the mathematical conception, and that every possible effort should be made to give the students a grasp of the physical conception. In teaching physics, as in all other subjects, every possible effort should be made by the teachers not to talk over the heads of their students; and I venture to suggest that the teaching at first should deal with the subjects in the simplest possible way. Otherwise it would be like talking in a foreign language.

I am strong in the belief that in the teaching of physics the physical concept should be fully developed before the mathematical demonstration is emphasized. I think it is a serious mistake to involve the student in the mathematics of some law before his interest is excited in the operation of that law. **And here the history of the unfolding of the law can also be employed to advantage.**

I also believe it is best to **demonstrate the elemental truths of science by the simplest possible experiments.** Here again it may be asked if I do not favor illustrations from practice. Yes, I do, but very simple illustrations until the truth is carried well home. I certainly do not believe in using highly technical illustrations except with students pretty well advanced. It seems to me to be most inefficient to worry beginners with minute details of corrections and the like, when they yet have no idea of the fundamental law. This sounds very trite, but is there not much of this in our teaching?

Don't let us worry over accuracy to the fifth decimal place if the basis for the computations is still under suspicion.

I have expended much time and energy in the effort to show that the best, but not necessarily the only, training for the engineer is the combination of the college and the school experience. The latter may not be necessary for the scientist; it is absolutely necessary for the engineer. It is not theory **or** practice, but theory **and** practice.

Too great dependence on lectures tends to superficiality. This should be corrected by more recitations than lectures, and the rigid testing of the students' standing by intelligent and fair questions. Many honestly but erroneously believe that they know until they are put to the test. We have all had this experience ourselves.

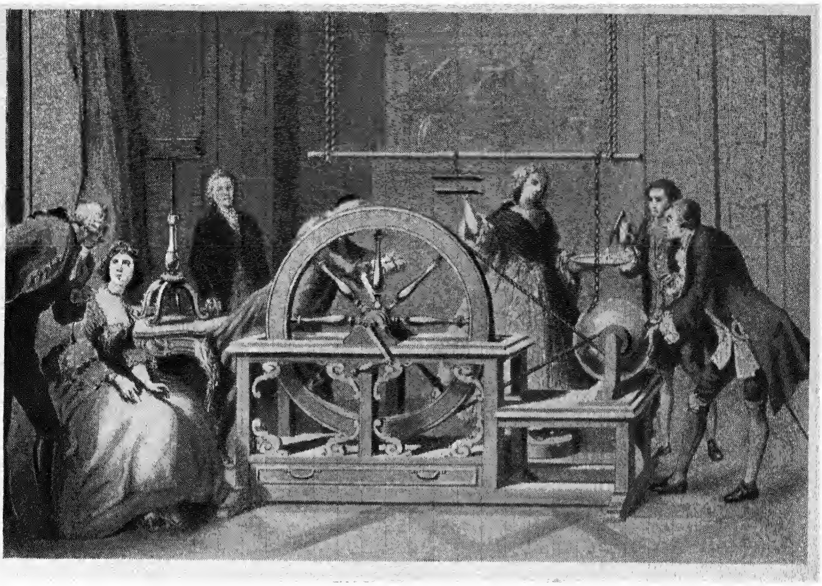
The longer I live the more I am convinced that much of the inefficiency we find in the working world, and I have had unusual opportunities for these sad experiences, can be traced back to building on weak foundations. The one who does not understand some proposition perhaps thinks he does understand; or perhaps he knows he does not understand but will not acknowledge it.

We are told that to be educated we must know one thing completely and have some knowledge of many things. I interpret this for my present purpose that we must know our fundamentals thoroughly and completely, and then have some knowledge of the many applications and illustrations of these fundamentals.

We can build on steadily with advancing years if we have the foundation; without this our edifice will be a ramshackle affair and become more so as we try to extend it.

## FRICTIONAL ELECTRICITY

It is said that about 600 B. C., Thales, a philosopher of Miletus, discovered that amber would attract light substances after being rubbed. Other learned men made similar discoveries, and during the middle ages there were occasional references to these experiments. It was not, however, until about 1570 that any really accurate observations were made. Since then numerous investigators have occupied themselves with what is known as frictional electricity, among them being Dr. Gilbert, Robert Boyle, Otto von Guericke, Sir Isaac Newton, Francis Hawksbee, Benjamin Franklin, Charles A. Coulomb and many others.



Slide No. 501
Hawksbee's Electrical Machine A.D. 1705

Otto von Guericke, about the year 1640, constructed an electrical machine consisting of a ball of sulphur mounted upon a shaft, and revolved by means of a crank. The ball was electrified by friction against the hands of one of the operators. About 1670 Newton repeated these tests, substituting a glass globe. In 1705 Hawksbee * produced a machine similar to Newton's.

Electrical machines were also made with glass cylinders and glass plates instead of spheres, and it soon became apparent that the size of the cylinder or plate, as well as the speed at which it was revolved, had something to do with the length of the spark, and the quantity of electricity obtained. And it was also noted, even if somewhat vaguely, that there was some relation between the amount of power applied and the electricity obtained, and that the big machines gave more impressive results than the little ones, at least from a spectacular standpoint. Of course, for exhibition purposes, larger and still larger machines were constructed. Probably the most enormous contrivance of this kind was displayed at the Panopticon in London, nearly a century ago.

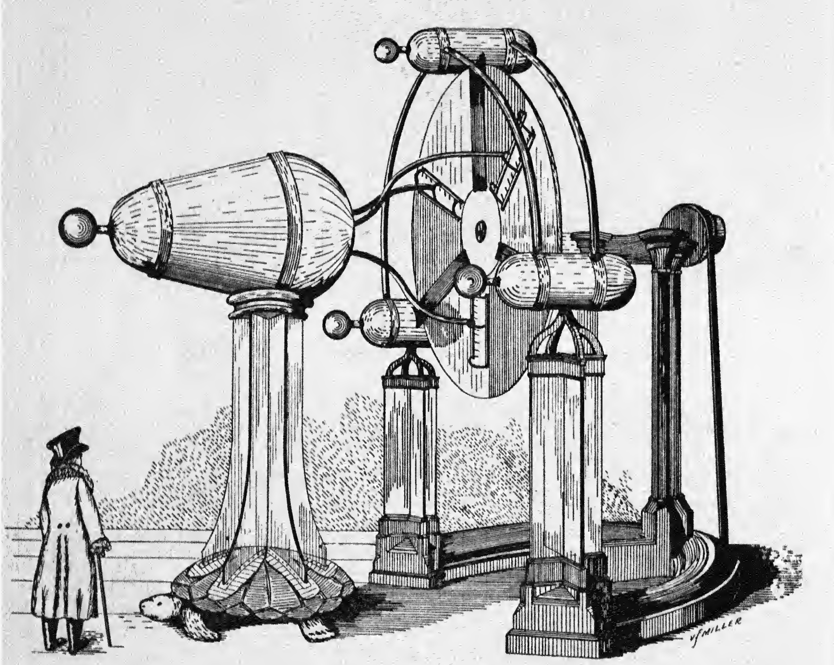
This machine was designed by Mr. Warner,*2 and was over twenty feet in height. Its revolving glass plate was ten feet in diameter. Under favorable conditions it gave a spark over two feet in length.

Incidentally, it is a little difficult to decide why a real or imitation tortoise was used to support the large insulator and prime collector.

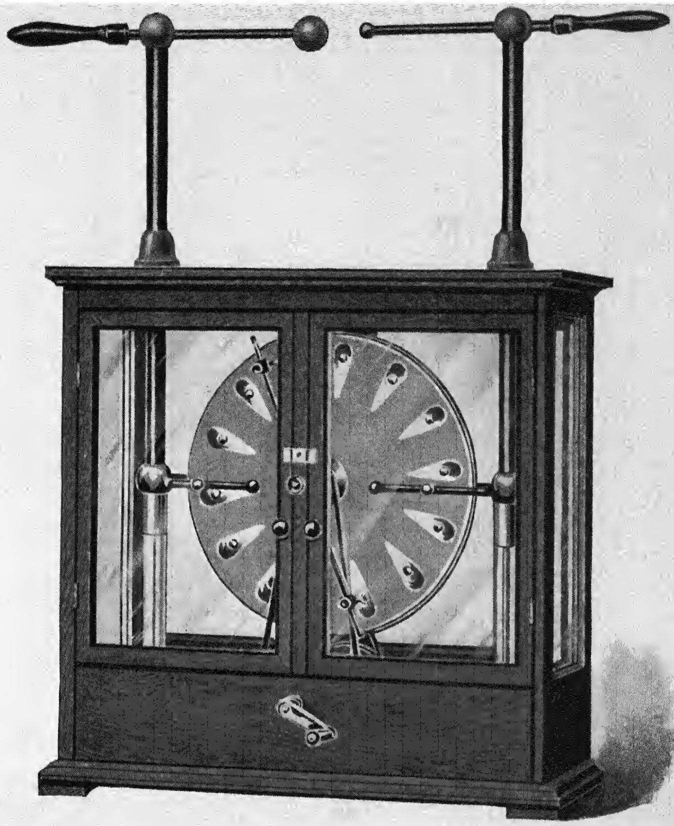
Numerous types of static machine were invented in addition to these, many of which were more efficient than Warner's, although much smaller in size. In fact a machine, which depends upon induction instead of friction, invented by Holtz of Berlin in 1865, gives a spark the length of which is over half of the diameter of its revolving plate.

* From "Leçons de Physique"—Abbé Nollet, 1767.

*2 From "Circle of Sciences" Edited by James Wilde, London




Slide No. 502
Warner's Electrical Machine



Slide No. 503
Wimshurst's Electrical Machine

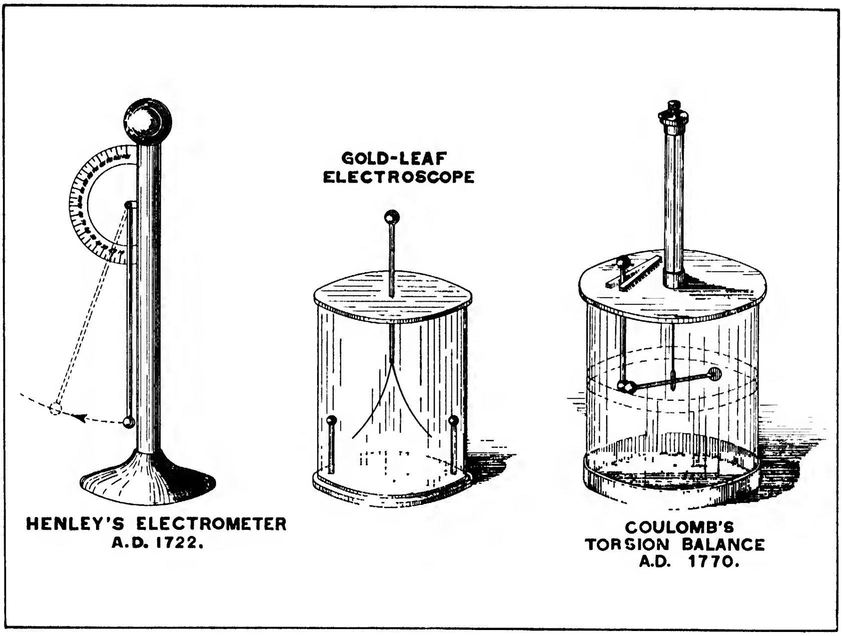
A still more efficient machine was invented by Wimshurst, which is also self-charging. Apparatus of this type is usually inclosed in a glass case containing a dish of chloride of calcium or some similar deliquescent material to absorb the moisture from the air and thereby improve the insulation. The case also served to protect the machine from dust and atmospheric impurities.

The Wimshurst machine is used in Roentgen ray experimental and similar work.

We can give but scant consideration to this subject, but wish to call attention to the fact that while the study of static electricity has for some time been neglected in the high schools, an eminent authority is emphatically of the opinion that the proper teaching of electricity is impossible unless we give static phenomena the attention which their increasing practical importance demands.

## ELECTROMETERS

An early attempt was made to produce some contrivance operating upon the repulsion principle, whereby the extent of charge or degree of




Slide No. 504
Henley's Electrometer, Gold Leaf Electroscope and
Coulomb's Torsion Balance

electrification of insulated bodies could be determined. Among the first was Henley's electrometer.* (Slide No. 504.)

The principle and operation of this apparatus is obvious. When mounted on a charged conductor, the pendulum will be repelled, and the amount of charge will be roughly indicated by the quadrant index. Instruments of this type were used which antedated Henley's, but there is no well authenticated proof that they were ever of value in connection with quantitative measurements.

A similar contrivance, consisting of two gold foil strips suspended from a conductor, is also shown on this slide.

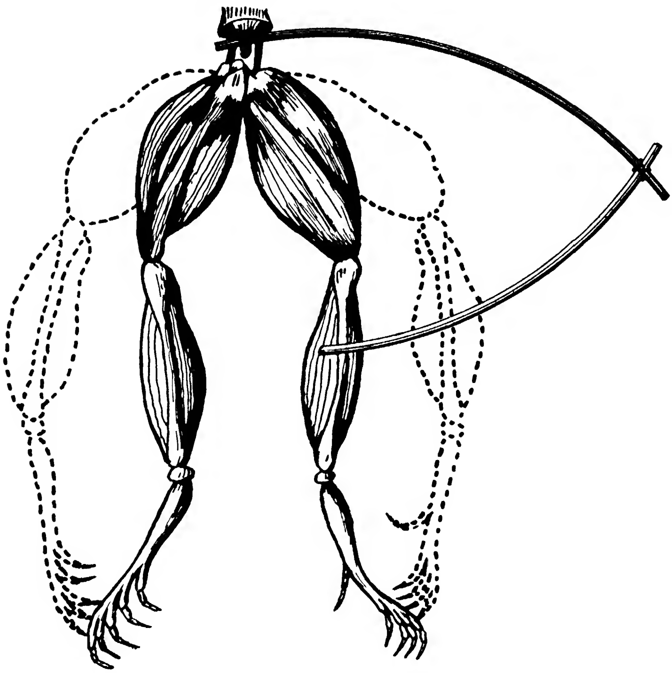
Coulomb *2 in 1770 was among the first to attempt the construction of an instrument by means of which electrical forces could be measured and subjected to mathematical analysis. His apparatus consisted of a glass case within which there was a small gilt ball fastened to a light non-conducting rod. This rod was suspended by a silver wire. Another ball in a fixed position was charged from a suitable source, and the deflection due to repulsion was noted. Coulomb found by means of this, the predecessor of all real electrical measuring instruments, that: **"The force of electrical repulsion varies inversely as the square of the distance."** This is the **first** quantitative electrical law which was established experimentally.

Quantitative measurements of static charges were necessarily attended with enormous difficulties owing to the very high potential of these charges, and their consequent tendency to dissipate rapidly unless the atmospheric conditions were exceptionally good.

* From "Philosophical Transactions." 1772

*2 Charles Augustin Coulomb, 1736-1806.

## GALVANIC ELECTRICITY



Slide No. 505
Galvani's Experiment
With a Frog's Legs
About A.D. 1786

But a new impetus was given to electrical investigations by the great discovery of Galvani * about 1786.

By accident, he found that the legs of a freshly skinned frog would twitch when the lumbar nerves were connected with the leg muscles by means of a suitable metallic conductor.

The history of Galvani's experiments has been translated from the original *[2] and is found in Chapter VI, of Professor John Trowbridge's interesting book, entitled: "What is Electricity?" *[3] from which we quote by permission:

"His (Galvani's) own account of the beginning of his experiments is extremely interesting, for it shows that he was not anxious to make it appear that he was the first to notice the strange phenomena which proved to have such far-reaching results. He says:

" 'This is the way the thing happened. I dissected a frog and prepared it as is shown, and laid it on a table upon which stood an electrical machine, far from the prime conductor, and not in a straight line with it. When one of the servants, who was at hand, touched with the point of the dissecting knife the inner lumbar nerve of the frog, all the muscles of the thighs appeared to contract as if under the influence of powerful cramps. The assistant thought that the phenomenon occurred when a spark passed between the conductors of the electrical machine. Astonished by this new

* Luigi Galvani (1737-1798), Professor of Anatomy at the Institute of Bologna.

*[2] De Bononiensi Scientiarum et Artium Instituto atque Academia Commentarii, tomus VII.

*[3] D. Appleton & Company, Publishers, New York and London.

phenomenon, he turned to me, I being occupied in other matters and absorbed in thought. Thereupon I was inflamed by an incredible haste and desire to prove * the same, and bring the hidden mystery to light.'

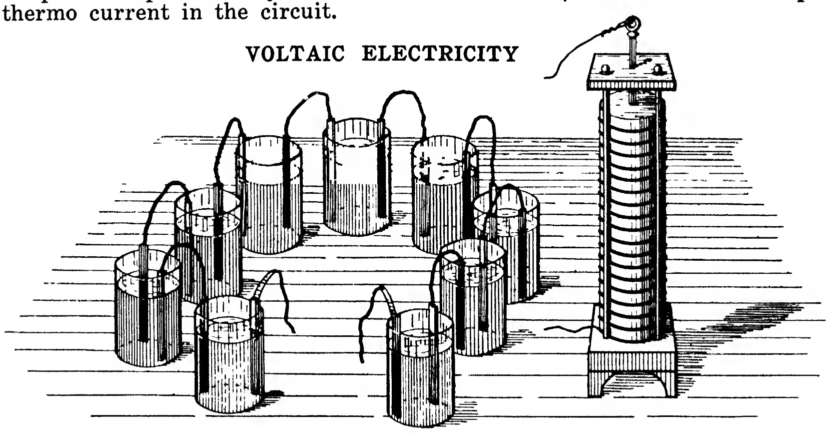
"Here, with extreme candidness and generosity, he gives full credit to his assistant for the accidental discovery. He traced the cause of the strange convulsions to the working of the electrical machine, and found that discharges of lightning could also produce the movements of the muscles of the frog's legs. He continues thus:

"'After I had investigated the effects of atmospheric electricity my heart burned with desire to test the power of the daily quiet charge of electricity in the atmosphere.' He had noticed that the prepared frog's legs, bound up with brass hooks on an iron railing, showed the same contractions, not only in the case of thunderstorms, but also under a clear sky. He was thereupon led to study the effects of touching the nerves with different metals and with non-conductors, such as glass and wax. He found that when the circuit between the nerves was made by two different metals, powerful contractions ensued."

Galvani attributed this effect to positive and negative charges which he assumed existed in the nerve and muscle. "The twitching of the frog's legs served him for a galvanometer—a sensitive indicator of the electrical current which was excited in the circuit of the metals and the muscles and nerves of the frog. A new instrument in physical science often opens a great field of discovery. The frog's legs in the hands of Galvani and his co-workers proved to be such an instrument.

"It was not a difficult step to take from the standpoint of Galvani to that of Volta. The instrument was at hand and the phenomenon had been observed. Galvani attributed the action to the vital electricity of the nerves and the muscles of the frog." The facts are that the motion might have been caused by chemical action on one of his conductors, due to moisture in the nerve or muscle; or, it may be that the two conductors had an imperfect contact where they crossed, and that a small current was developed at this point, due to the presence of some liquid. Finally, the results obtained could be accounted for on the supposition that thermo electricity was the real agent; and that, owing to the fact that the two metals may have been held between the fingers at their junction, there was a difference in temperature produced by the warmth of the hand, which would develop a thermo current in the circuit.

## VOLTAIC ELECTRICITY



Slide No. 506
Couronne de Tasses & Volta's Pile
The First of all Electric Batteries A.D. 1800

* Probare—used in the sense of "test."

It is universally admitted that it was Volta * who proved that a current could be produced by the junction of two metals, and that the frog's legs did not produce electricity, but acted as an indicator of current, or galvanoscope. This discovery inaugurated what was called "voltaic" electricity.

It is uncertain whether Volta reasoned that the current was due to chemical action on one of the two metals he used to form his circuit, but his subsequent investigations seem to indicate that this was his supposition.

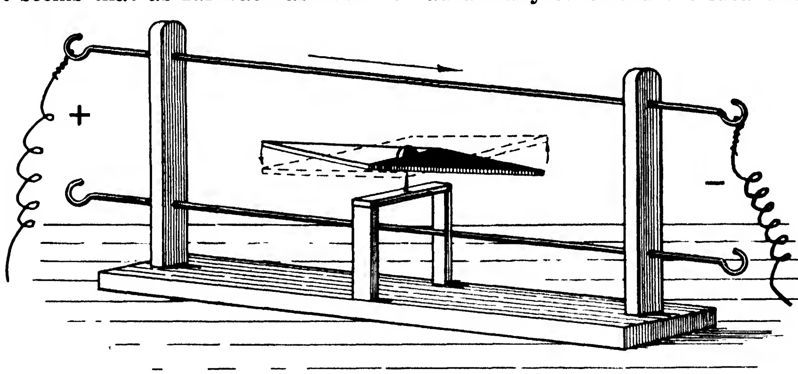
Volta followed up the hint obtained from the experiment with the frog's legs, and in the year 1800 produced his famous voltaic pile, which consisted of a series of alternate disks of zinc and copper, separated by moistened felt. Surprising results were obtained with this pile. He next invented his **couronne de tasses** (crown of cups), which was a battery of simple cells in series. Each cell was composed of a plate of silver or of copper and one of zinc immersed in brine. It is noteworthy that **zinc** was employed in this, the first of all batteries, indicating that in all probability Volta experimented with various combinations of metals, and finally gave preference to zinc. To this day zinc is still used for the active pole of voltaic cells, and there is no substance which is equally good from a practical standpoint.

It may not be out of place to digress here for a moment and call attention to the crystal clearness of Volta's mind. Instead of indulging in abstract speculations, he utilized facts, and aided by them and a powerful imagination, made discoveries and inventions of inestimable importance.

Owing, probably, to the fact that "frictional" electricity is of very high potential, compared with "voltaic," it was for some time supposed that there was an actual difference between them; but Volta seemed to have had a clear conception of their analogy and deduced or learned by experiments that the electromotive force of a battery is increased by adding cells in series; and that the total e.m.f. depends directly upon the number of cells in the battery. In view of these facts, the name of the unit of electrical pressure, the **VOLT**, has been well chosen.

## OERSTED'S DISCOVERY

In 1820 Oersted *² made public a discovery of his which was equal in importance to Volta's. He found that a magnetized needle was affected by the action of an electric current. This was determined by experiment, but it seems that as far back as 1806 he had already conceived the idea which




Slide No. 507
Œrsted's Experiment
A.D. 1819

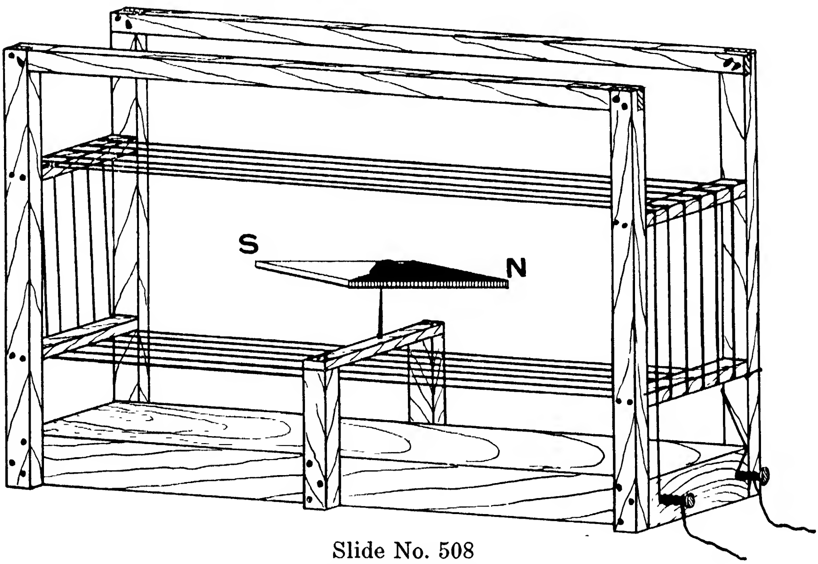
* Count Alessandro Volta (1745-1827), Professor of Physics at Pavia.
*² Hans Christian Oersted (1777-1851), Professor of Natural Philosophy, Secretary of the Royal Society of Copenhagen.

he later proved experimentally; and in 1813 Oersted stated: "It must be determined whether electricity in its most latent state has any action upon the magnet as such."*

In a "Historical Sketch of Electro-magnetism",*2 Oersted is given credit for having made the following discovery:

He found that the "magnetic property" of the current did not depend upon the kind or form of metal he employed; and that the magnetic needle would be deflected by using any conductor, "even a tube of mercury being effectual, the only difference being in the quantity of effect produced"; and that results were obtained even if "the conductor be interrupted by water, unless the interruption be of great extent."

## SCHWEIGGER'S EXPERIMENT




Slide No. 508
Schweigger's Experiment A.D. 1821
Showing the Effect of Several Turns of Wire

In 1821 Schweigger *3 placed a compass needle in the center of a parallelogram and wound several turns of wire around it, each turn being insulated. His apparatus is the great-grand-parent of all movable-magnet galvanometers, and was called the Schweigger Multiplier.

## AMPERE'S EXPERIMENTS

Soon after Oersted's discovery was made public Ampère *4 began his investigations. He reversed Oersted's experiment (Slide No. 509), and showed the action of a magnet on a movable circuit by means of a rectangular movable frame suspended from mercury cups. When a magnet is placed near this frame and current is flowing, the frame will be attracted by the magnet.

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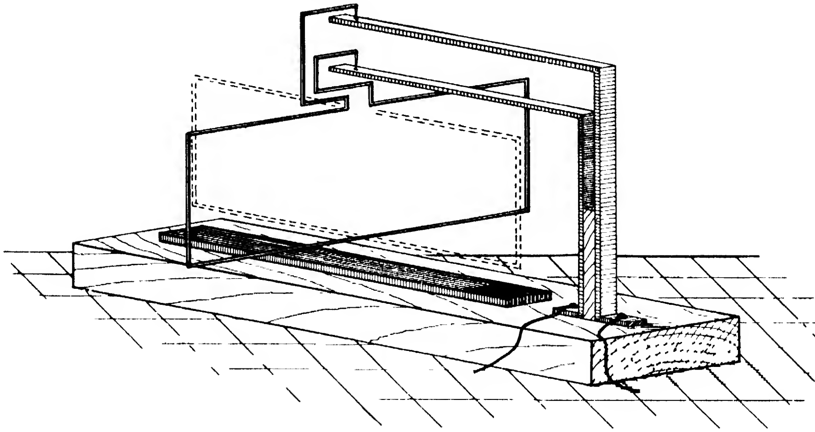
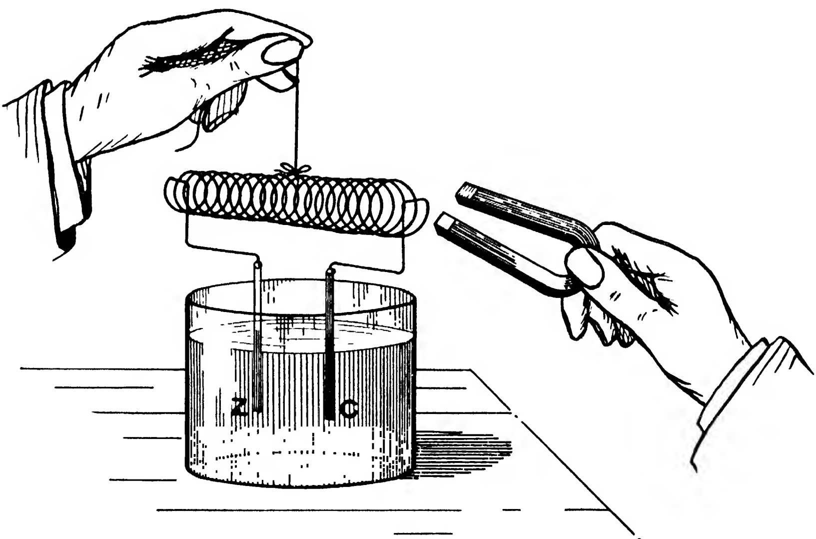
* "Researches into the Identity of Electrical and Chemical Powers." Paris, 1813.
*2 "The Annals of Philosophy," Vol. II, 1828.
*3 Johann Solamo Christoph Schweigger.
*4 André Marie Ampère (1775-1836), Professor at the Polyclinic School, and at the College of France.



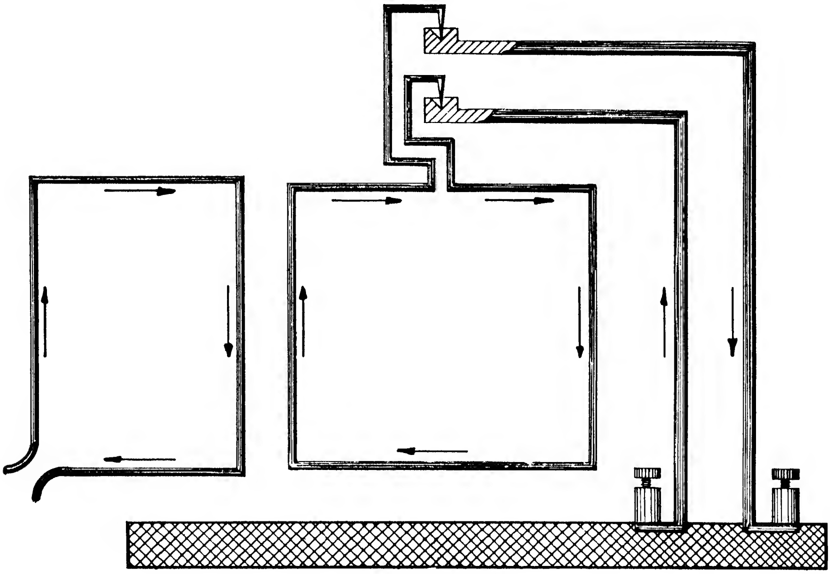
Slide No. 509
Action of Magnet on Movable Circuit
Ampere's Experiment A.D. 1820

Another of Ampère's experiments was performed by means of a very simple piece of apparatus, which combined in convenient form a spiral or solenoid of copper wire, one end of which dipped into an acid solution. A strip of zinc was fastened to the other end, forming a simple cell, the current from which flowed through the solenoid. When suspended, as shown, it will be attracted by a magnet. Some historians state that Ampère experimented with a spiral before he used the parallelogram just shown.*




Slide No. 510
Ampere's Experiment Showing the Action of
a Magnet on a Solenoid. A.D. 1820

* "Historical Sketch of Electro Magnetism" in the "Annals of Philosophy," 1821, Vol. II, Pages 277 and 278.



Slide No. 511
Ampere's Experiment. The First Electro-dynamometer. A.D. 1820

Ampère also discovered the effect of one current upon another and founded the science of electro-dynamics. His apparatus was exceedingly crude and the conclusions he arrived at, as well as his deductions and predictions, were due to his brilliant mathematical analysis and extraordinary ability.

If we except Faraday, it is probable that no other man of his era accomplished as much toward the advancement of electrical knowledge as Ampère. The fact that the unit of current was named in his honor is only a fitting tribute to his genius.

## FARADIC ELECTRICITY

In 1821 Faraday * caused a piece of horizontal wire, carrying a current, to rotate across the vertical lines of a magnetic field. This was the first electric motor. Between 1831 and 1832 he discovered induced currents and established the fact that when a circuit is first made it will induce a current in a nearby circuit; and when the circuit is broken another induced current is obtained. The induced currents are in both instances momentary.

Faraday also discovered that a moving magnet would produce an induced current in a nearby coil, and made important discoveries in electromagnetism, which lead to the eventual perfection of the electromagnet.

## ARAGO'S DISCOVERY

In 1824 Arago *2 made a remarkable discovery. He mounted a horizontal disk of copper on a shaft and rotated it by means of clock work. He found that if he placed a compass needle over this disk, the needle would tend to move in the direction the disk was rotating, and would finally spin around on its own axis. (See Slide No. 554.)

* Michael Faraday (1791-1867).
*2 François Jean Dominique Arago (1786-1853)

This phenomenon was investigated by Babbage * and Sir John Herschel, but it was Faraday who finally solved the problem and decided that the motion of the needle was due to electric currents induced in the copper disk while in motion.

The same effect is produced by using powerful permanent magnets, with small air gaps between their poles, and rotating the disk between them. It will be found that more power is required to turn the disk when the magnets are in place than when they are removed. When an apparatus of this type is used in connection with a watt-hour meter it is called a magnetic brake. (See Slide No. 554.)

## OHM'S LAW

Ohm first published his remarkable mathematical theory *[2] in 1827, but it was not until the Copley Medal was awarded to him by the Royal Society in 1841, that the importance of his work was recognized.

But many experimenters had previously formed adverse theories and it took time to convert them. Ohm's law was also received with disfavor by that class of inventors or investigators who imagined that electricity might be a means for getting something for nothing, who wanted to believe that electrical output could exceed input and that it could serve them in their efforts to create energy. Many experimenters had made discoveries, and

# OHM'S LAW

CURRENT = $\dfrac{\text{ELECTROMOTIVE FORCE}}{\text{RESISTANCE}}$

$$I = \frac{E}{R}$$

AMPERES = $\dfrac{\text{VOLTS}}{\text{OHMS}}$

RESISTANCE = $\dfrac{\text{ELECTROMOTIVE FORCE}}{\text{CURRENT}}$

$$R = \frac{E}{I}$$

OHMS = $\dfrac{\text{VOLTS}}{\text{AMPERES}}$

ELECTROMOTIVE FORCE = CURRENT X RESISTANCE

$$E = I \cdot R$$

VOLTS = AMPERES X OHMS

Slide No. 512

* Charles Babbage, M.A., Fellow of the Royal Society and inventor of the famous Babbage Calculating Machine or, as he called it, "Difference Engine."

*[2] "Die Galvanische Kette Mathematisch Bearbeitet." By George Simon Ohm (1787-1854).

had commented on various phenomena, but the connection between them, their inter-relationship or "zusammenhang" was imperfectly understood, and not at all appreciated.

What, then, is this law, that made order out of chaos? Simply this:

Let us give a few minutes' consideration to the first of these formulaes, which makes the others self-evident. "Current equals electromotive force divided by resistance"; or, amperes are the result of volts divided by ohms. What does it mean? It means that when we have a definite electrical pressure or voltage, the current we will obtain will depend upon the materials we use to transmit this current; and that the output of any cell, battery or other source of direct current depends upon the diameter, length and nature of the conducting materials. And, most important of all, it makes the fact obvious that no substance is a perfect conductor of electricity; and that, therefore, all conductors have resistance.

Before Ohm's law was published few seemed to have a definite conception of the relation between electromotive force and current. It was through Ohm's law that the first clear understanding of resistance was obtained.

An emphatic evidence of the significance of Ohm's law is obtained by reviewing the work of other famous experimenters of about the same period. For instance: Ampère was a great mathematician, a "lightning calculator" in fact, yet he seems to have attached slight importance to the conductivity of the materials out of which he constructed his parallelograms; he was absorbed in calculations relating to the elementary laws of electro-dynamics, and consequently specific conductivity was not his objective goal. That he did not discover Ohm's law is undeniable, but his researches prove that he got as close to this "law of nature" as any man could get without actually establishing it.

Volta found out that the electromotive force of a battery depended upon the number of its cells. He might have added to his fame, and anticipated Ohm, if it had occurred to him that the output from his battery could be considered quantitatively as well as from the standpoint of potential; and that the current which a voltaic battery will produce depends upon the resistance of the circuit, of which its own internal resistance forms a part.

Oersted discovered that all conductors through which current was flowing acquired magnetic properties and stated that the "quantity of effect produced" varied with the materials employed. But the effect he was investigating was the action of a current upon a magnet. Of course, now that we know it is so, it is easy enough to say that he might have deduced that the extent of magnetic effect he obtained depended upon the strength of his current and that the flow of current depended upon the conductivity of his materials.

Another man, not so well known to fame as he might have been, was Moll.* He got so close to the truth that it scorched him, so to speak. After experimenting with a battery having a large number of cells, he stated: "The magnetic power was very great when the connecting wire was of considerable thickness (.2 of an inch), but when a much smaller platinum wire was used (1/100 of an inch), the power diminished considerably." *2

You see he had all the apparatus required to establish the fact that Current = e.m.f. ÷ resistance. He noted that the power diminished when he used a fine wire and was greatest with a thick wire. Does it not seem somewhat strange that he did not think a step further, and come to the conclusion that, since he was using the same source of current, the decrease in effect he noticed was not only due to the diameter and material of the wire, but also to its length? It was such a fine chance to reason out that the conductivity of a wire depends directly upon its diameter, and inversely upon its length. And then he could have reversed his formula, introduced the word "resistance," and said: "The resistance of a conductor is directly as its length, and inversely as its diameter." That would have been a solid foundation to build Ohm's law upon.

* Gerrit Moll, of Utrecht, Holland.

*2 "Journal de Physique," 1821, and "Annals of Philosophy," 1821, Vol. II, P. 288.

Schweigger knew that as a rule, he obtained better results with his multiplier or galvanometer when its field contained several turns of wire; but he had also found out that increasing the number of turns did not always give greater sensitivity. Of course, the reason was that the increased number of turns would be an advantage only when the e.m.f. of his battery was increased in such proportion that sufficient current would be obtained in spite of the increased resistance due to the added turns.

Each of these investigators, and many others, had discovered one or more facts, but, as Randall states: "The utility of any bit of human knowledge, taken by itself is not great. Its full significance is not realized until we get a clear understanding of the relation of one fact to all others. Then only can we apply knowledge to maximum advantage." That is what Ohm did; he made no discoveries, but he correlated facts and thereby opened wide the door to systematic electrical progress. And progress was rapid after 1841.

Our story of the accomplishments of pioneer physicists is necessarily superficial and incomplete. There were many earnest workers whose names we have to leave unmentioned, although their investigations were of importance.

Nor can we give proper consideration to the study of magnetism in these lectures, except insofar as it relates to the dynamics of measurement apparatus, but we intend, later on, to demonstrate that all of the experiments so far shown apply to measuring instruments; that, in fact, they are the foundations upon which the art of electrical measurement was built.

## JOSEPH HENRY'S WORK

But in passing we pay tribute to Joseph Henry, who, according to the "Encyclopaedia Britannica" (from which we quote), was acknowledged to be "the foremost of all American physicists of his era. He was the first to demonstrate experimentally the difference in action between what he called a 'quantity' magnet, excited by a 'quantity' cell consisting of one pair of elements, and an 'intensity' magnet wound with a long, fine wire coil, excited by an 'intensity' battery of many elements." The results of his experiments were made public in 1828 and 1829, so that he may possibly have had the benefit of Ohm's theory, published in 1827. However this may be, Henry shares with Faraday the honor of having developed the electromagnet, and there is no question of his having worked independently while an instructor in the Albany Academy and that he had a clear conception of the relations between electrical pressure, current and resistance.

"In 1831 Henry discovered the conditions necessary to obtain the greatest magnetic effect from any given bar of iron with any given battery; and guided by these discoveries, he constructed a magnet which supported nearly three tons."

The picture you now see (Slide No. 513) was made from an illustration prepared in 1872, and shows the "Great Electromagnet of the Stevens Institute of Technology," as it looked at that time. This magnet was identical with Henry's except in some minor details. It is still in good order and in use in the lecture room.

"Thus to our countryman belongs the honor of being the first to **present freely to the world the knowledge of fundamental facts absolutely essential for the subsequent invention of the electromagnetic telegraph;** which invention in all its essential principles is also due to Henry, who in 1832 at Albany, and during the following years at Princeton, exhibited his apparatus for transmitting electromagnetic signals to a distance." *

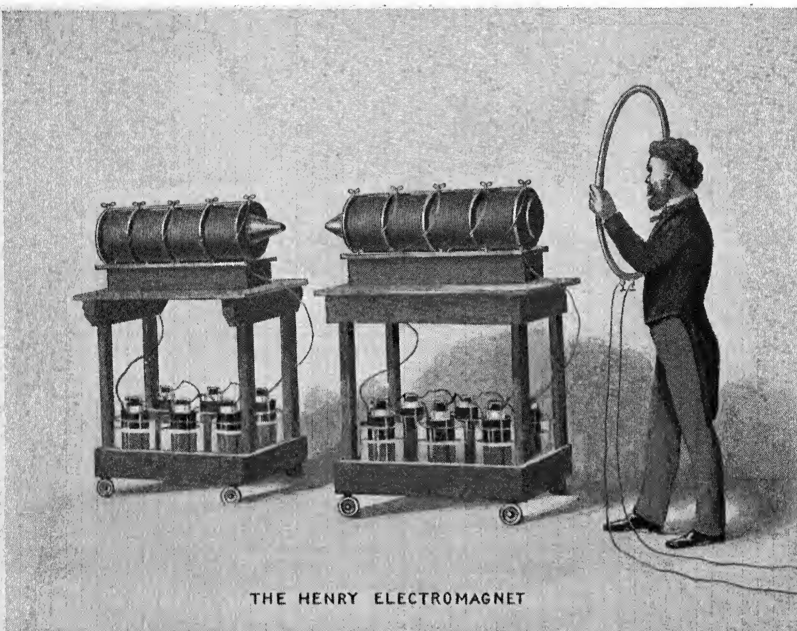
His work focused the attention of others upon the practicability of using high-resistance electromagnets in connection with the transmission of signals by means of electricity, and after development by Morse, Froment, Siemens, Wheatstone, Latimer Clark and others eventually resulted in the perfection of the electric telegraph.

* From "The Earth A Great Magnet"; a lecture delivered before the Yale Scientific Club, February 14, 1872, by Prof. Alfred Marshall Mayer, Ph. D., of the Stevens Institute of Technology.

Telegraphy constituted the first important attempt to use electricity commercially on any extensive scale; and had a marked influence in creating a demand for test instruments of precision, because its successful and continuous operation with exposed wires and crude insulators, made exact measurements under varying weather conditions a necessity.

Henry derived no pecuniary benefit from his discoveries and experimental work, but will always be held in honored memory by his countrymen and by scientists the world over. He was more than famous, since: "He was a man of varied culture, of large breadth and liberality of views, of generous impulses, of great gentleness and courtesy of manner, combined with equal firmness of purpose and energy of action."

## THE HISTORIC HENRY ELECTROMAGNET OF THE STEVENS INSTITUTE OF TECHNOLOGY



THE HENRY ELECTROMAGNET

Slide No. 513

[This electromagnet was built about 1870 by Wallace & Sons, of Ansonia, Connecticut. Swedish iron was used in its construction because at that time this was supposed to be the best magnetic material available

The core of the magnet was made hollow because at the time it was thought that magnetism resided largely on the surface of iron It was wound with large size "kerite" insulated copper wire, approximately 0 25 inch in diameter, because at the time the only available current was that from large Bunsen primary batteries The winding was placed in sections on large brass spools split longitudinally to interrupt the electrical circuit of the spool. Two vertical hollow cores carrying the magnetizing spools were set upon a rectangular iron base, and pole pieces were laid on the top when the apparatus was used as a horseshoe magnet. For some experiments the two cores were laid horizontally in one line and the coils connected either to produce adjoining like poles or adjoining opposite poles. The pole pieces were also made hollow for experiments with polarized light.

About fiteen years ago the "kerite" insulation had deteriorated, causing short-circuiting in the coils The wire was removed from the spools, the old insulation removed, and the wire was then re-insulated with cotton braiding, and the magnet coils were rewound. It is interesting to note that the new insulation occupied more space than the old insulation, so that fewer turns could be wound on each spool.]

ALBERT F. GANZ

## THE COMMERCIAL APPLICATION OF ELECTRICITY

One of the old writers, while commenting on the results obtained by empiricists of his day, offered this quaint comment: "Bare curiosity in one age is the source of the greatest utility in another, and what has been frequently said of the chemist, may perhaps be applied to every other kind of virtuosi. They hunt, perhaps, after chimeras and impossibilities, and find something really valuable bye the bye." *

This statement is pertinent to investigations in electricity and magnetism. For centuries the old philosophers studied and speculated, propounded theories and wrote ponderous treatises, but it was not until the year 1837, when the electric telegraph first came into public use, that any of their pioneer work became of real practical value, and it took twenty-five years more before electricity was of great commercial importance.

And it may be in place to remark here that while there is generally no doubt about the sincerity of the utilitarian or the enthusiast who works only for the advancement of science and the benefit of mankind, there is also no questioning the fact that if an art is to develop and prosper, it must have intrinsic value, so that it may be put upon a solid financial basis. Therefore, just as soon as there was any prospect of using the electric current with economy and efficiency for performing useful work, the art developed with amazing rapidity. Practical men as well as scientists, established the commercial and scientific importance of the laws relating to electrical currents, laws long before promulgated by Coulomb, Ampère, Oersted, Volta, Ohm, Faraday and others.

With a rapid increase in the commercial use of electricity came a demand for some apparatus by means of which the capacity and efficiency of generators and motors could be accurately determined. Of course, at the outset spectacular demonstration sufficed, and if we refer to Deschanel's Philosophy *[2] we will find a so-called test of a Wilde's dynamo and learn that (in the year 1866) "by means of the current from this machine, driven by 15 horse power, the electric light was maintained between two carbons as thick as a man's finger, and a bar of platinum two feet long and a quarter of an inch in diameter was quickly melted."

Think of the absolute lack of simplicity, accuracy, and economy of such methods! Fifteen horse power was required to produce one arc light, and several hundred dollars' worth of platinum was fused to demonstrate the heating effect of a current. Is it any wonder that a demand arose for apparatus by means of which quantitative electrical measurements could be made with accuracy and certainty?

## THE DEVELOPMENT OF ELECTRICAL MEASUREMENT APPARATUS

The problem of devising electrical instruments of precision has engaged the attention of many distinguished physicists and engineers. Prominent among these were Marcel Deprez and Prof. A. d'Arsonval, in France; Kelvin, Ayrton, Perry, Cardew and others in England; Siemens, Kohlrausch, Hummel and others in Germany.

Not one of these scientists succeeded in producing an electrical indicator which was perfect in principle and operation, although many types were placed upon the market, and some were extensively used, until they were wiped out of practical existence by the advent of the Weston instrument.

We would like to be able to state definitely how many models were made, tested, and finally rejected; and when the fundamental idea was at last embodied in a satisfactory model, how much more work was required to invent and manufacture the tools and special devices needed to produce the instruments commercially on the interchangeable plan.

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* "Lectures on Natural and Experimental Philosophy." George Adams, London, 1799.

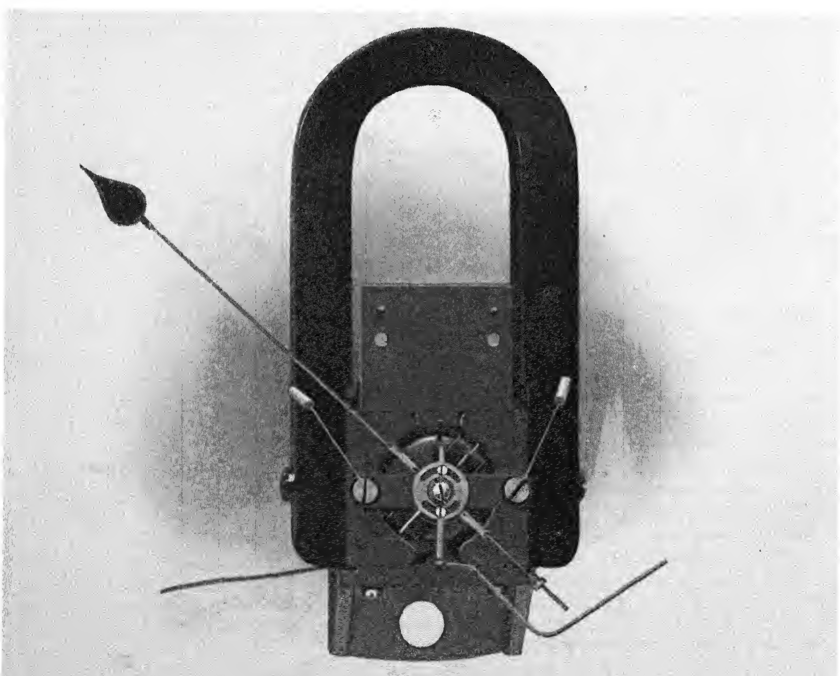
*[2] Revised edition, 1883, P. 795.

If, also, we could tell you all about the financial wars which were waged over these instruments; of the vast sums of money which had to be spent to prevent infringement; of the persistent attempts on the part of unscrupulous manufacturers to "dodge" the patents; of the misrepresentations of imitators; and in spite of all obstacles, of the final world-wide recognition of Weston superiority, we could tell you a very interesting story, but unfortunately it can be told properly by only one man, Dr. Edward Weston himself, and he at present continues to be too much occupied with inventions and research work to find time for writing a memoir.

We will, therefore, limit ourselves to a few facts. As far back as 1871, when Dr. Weston was interested in the electro deposition of metals, he invented a plating dynamo, and no doubt even then felt the need of good indicating instruments, but he transferred his attention from electro plating to the larger problems of designing and manufacturing generators for electric lighting and produced a series of machines known as the Weston dynamos, and the instrument problem had to wait.

When the Weston arc and incandescent lamps were being developed and tested the need of good voltmeters and ammeters again became urgent, and he gave the subject serious consideration, because it irritated him to be hampered in his work by being obliged to spend hours in determining electrical quantities with accuracy, knowing that the same results could be obtained in a few seconds, if only the proper instruments were in existence.

However, it was only a few years before 1888 when Dr. Weston finally had time to spare in which to give the instrument problem thorough attention; and even then he was also occupied in experimenting with his cadmium



Slide No. 514
A Typical Weston Direct Current Movable Coil System

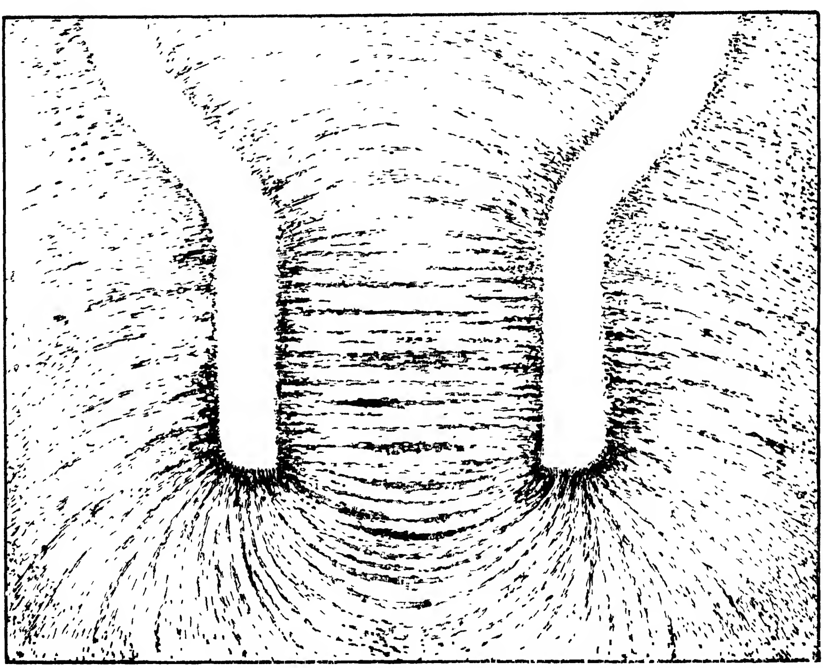
cell, which afterwards became the world's standard of electromotive force, and with his manganin, nickelin and other alloys for producing wire having a negligible temperature co-efficient, and with many other problems.

It is evident he reached the conclusion that for direct current measurements the best results are obtained by means of the permanent magnet movable coil instrument; so he invented that first, and then turned his attention to apparatus for the measurement of alternating currents, and developed the dynamometer types of voltmeters and wattmeters.

Although when first placed on the market there was considerable skepticism about the possibility of making a magnet permanent, Weston instruments were at once adopted by engineers, by physicists and by experienced experimenters, and became what they have since remained, the world's standards.

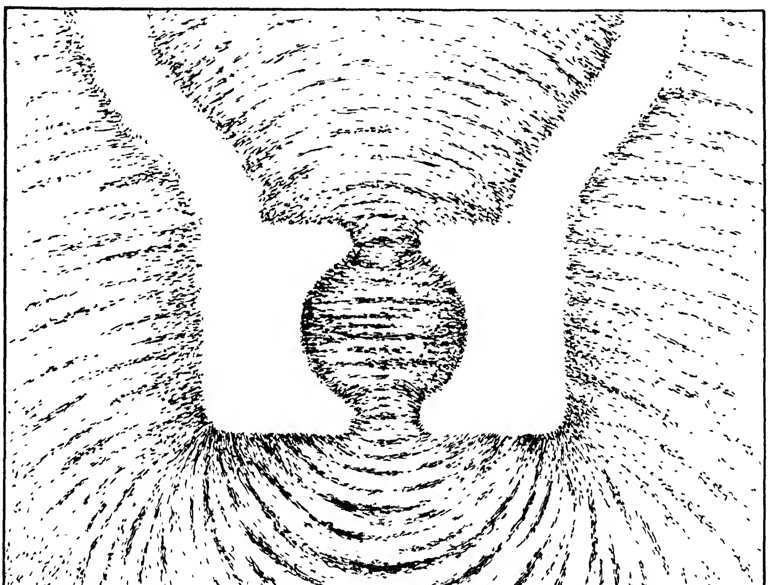
## THE PEDAGOGIC VALUE OF WESTON INSTRUMENTS

For several years past Weston voltmeters, ammeters and wattmeters have been considered indispensable in the proper equipment of the school laboratory. But, although they are now placed freely in the hands of the student as aids in the solution of many electrical problems, a misconception still exists in the minds of many in relation to the mechanical construction, as well as the electrical functions of these instruments. Since a thorough mastery of the principles upon which Weston instruments are based, is in itself no insignificant accomplishment, suppose we dissect one of them and consider the parts in detail.



Slide No. 515
Lines of Force of a Weston Permanent Magnet

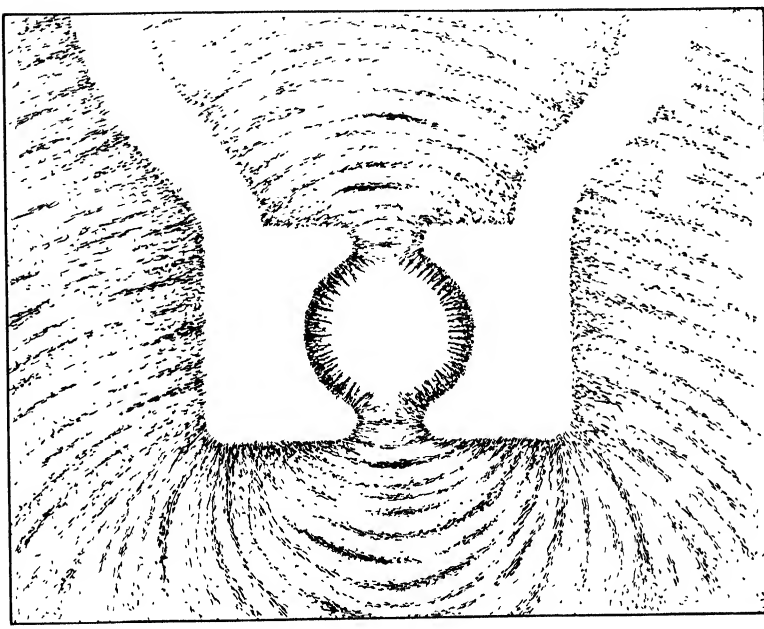
We note that prominent parts are a magnet and a movable coil, and that the latter is arranged so that a current may flow through it. We may, therefore, conclude that Ampère's laws apply to its operation, but it should be noted that while Ampère's parallelograms serve very well to demonstrate a fundamental principle, neither their design nor construction made the apparatus anything more than indicators of current. As such they serve their purpose excellently, but in an instrument of precision each operative part must be so designed and proportioned that the apparatus as a whole will give uniform results. To fully comprehend how this is accomplished in the Weston instruments, let us begin with the magnet, or rather with the outline of the magnet produced by iron filings. (Slide No. 515.) As you see, the effect of these lines of force is made visible in every direction, showing that many of them are not utilized in the operation of the instrument; but on the other hand, those which are to form the field in which the movable coil rotates consist of nearly straight lines between the poles of the magnet. But they are not yet straight enough to suit. Therefore, the next step in the construction of the system is the addition of pole pieces. (Slide No. 516.)



Slide No. 516
Lines of Force of a Weston Permanent Magnet with Pole Pieces

You will notice that the addition of these pole pieces has the effect of concentrating the magnetic lines which we wish to use, and that they form a ring on the faces. But there are still some lines in the center which we wish to straighten out. We therefore make a further improvement by adding a core of soft iron. (Slide No. 517.)

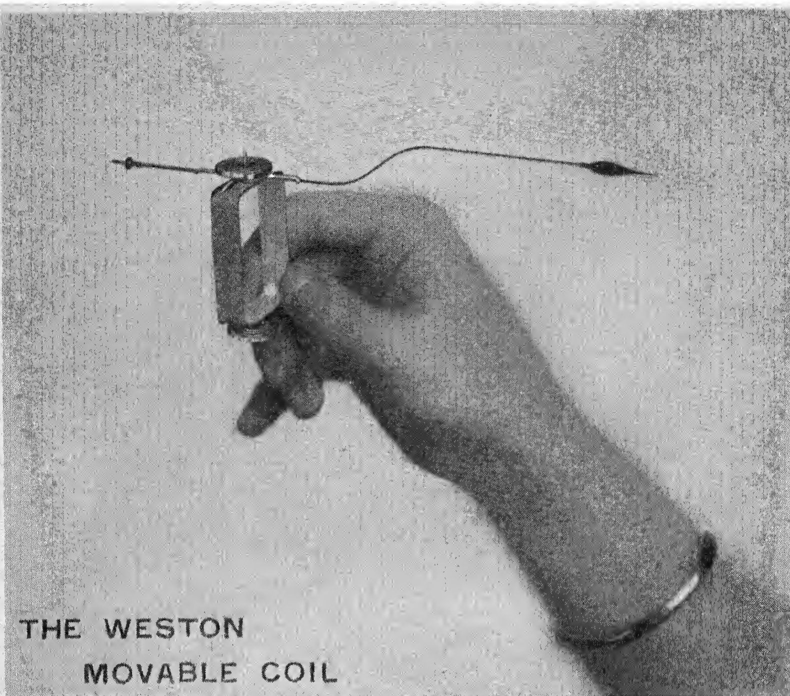
We now have a perfect magnetic field which is not only intensely concentrated, but, as may readily be seen, its lines are no longer parallel, but radial and uniform. The space represented by these lines, is, of course, the field through which the movable coil must pass when it rotates.



Slide No. 517

Lines of Force of a Weston Permanent Magnet with Pole Pieces and Core

## THE MOVABLE COIL




Slide No. 518

This coil, which might be called the heart of the movable system, is made of several turns of wire carefully insulated and wound upon an aluminum frame, and the parts are so designed and constructed that their weight is reduced to a minimum, which is very important since excessive weight in the movable system causes pivot friction and a rapid wearing out of the parts, as well as making the coil less responsive to small changes in current.

The coil shown is one from a switchboard voltmeter, its dimensions being roughly about 1 by 1⅜ inches. Of course the size of the coil depends upon the type of instrument of which it forms a part.

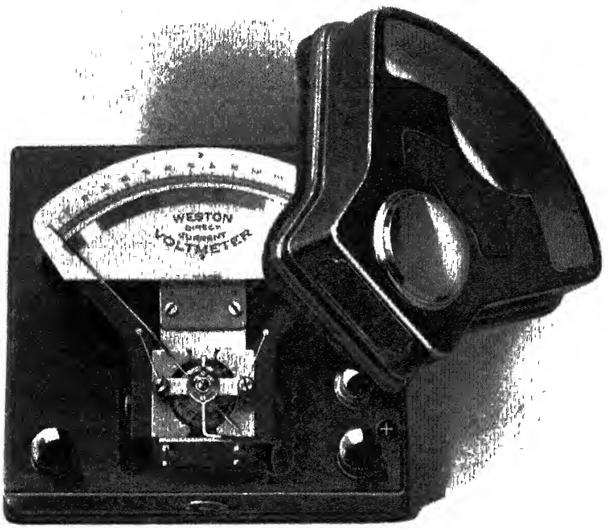
In a popular instrument, known as the Weston Model 280, the movable system weighs slightly less than three grains, although consisting of sixteen parts.

Some of these parts are so small that they must be examined under a magnifying lens in order to learn their exact form, and yet their mass is distributed with such care and exactness that the center of gravity of the movable coil is almost exactly aligned with the pivots. This alignment is perfected by means of balance nuts on the cross arms and pointer ends. Do not forget that this movable coil, although containing no iron, has all of the properties of a magnet when a current is sent through it; and, therefore, it will have polarity; and since it lies in an intense magnetic field it will have motion—due to the attraction between its poles and the opposite poles of the permanent magnet.

But because it is held in position by pivots and jewels, only rotary motion is possible. This motion is regulated by means of two springs, which also serve as current conductors, taking the place of the mercury cups used by Ampère.

When current is flowing a deflection will be obtained proportional to the strength of the current. A rigidly attached pointer moves over a scale and indicates the extent of the deflection, and for any given current flowing through the movable coil the deflection will always be the same.

## THE COMPLETE INSTRUMENT




Slide No. 519

A Weston Model 1 Voltmeter with its Cover Removed

Up to this point we have been considering the construction of the instrument from a purely mechanical standpoint, but, of course, it is obvious that the function of the instrument is in reality of an electrical nature. That is, it is intended to measure electrical quantities.

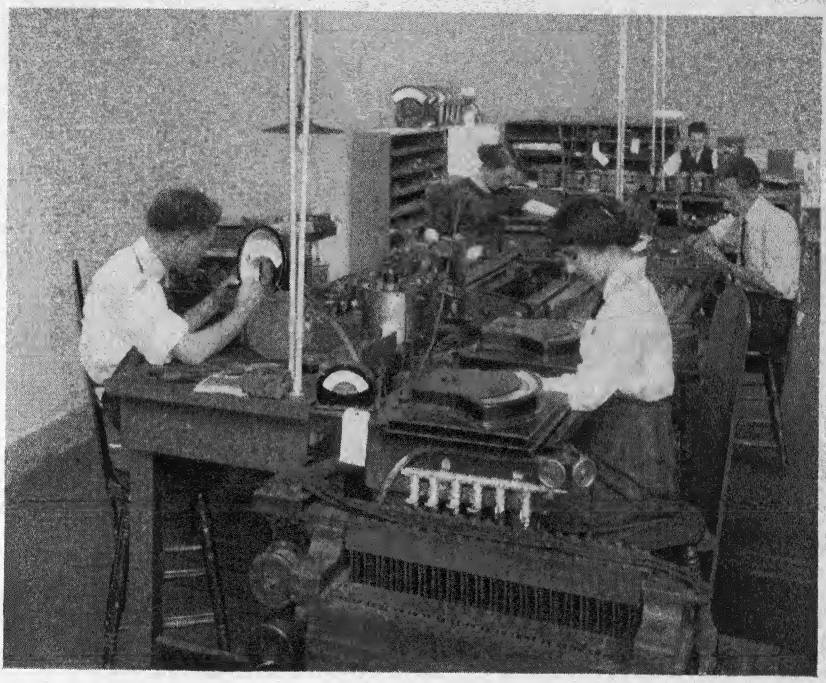
Hence, if the system is to serve as a voltmeter, a resistor has to be added in series. This resistor may temporarily consist of any suitable rheostat having sufficient adjustability and current-carrying capacity, provided it is not affected by possible changes in temperature.

In order that the deflections indicated by the pointer may be direct reading and represent known electrical quantities, it is necessary to calibrate the scale by reference to a master or laboratory standard.

The way in which this is done is to have a reader at the master standard call out the different values that are to appear on the scale of the instrument to be calibrated, and make a small pencil mark at 12, 15 or 30 cardinal points, the necessary number depending upon the character of the scale.

Slide No. 520
Inking In a Large Scale

The scale is then numbered with the serial number of the instrument for which it is intended and taken out and carefully inked in by an expert, after which operation the scale is again placed in the instrument and again checked with the master standard. The draftsman portrayed in this picture is engaged in completing the scale of an unusually large instrument which is intended for central stations.



Slide No. 521

Checking a Scale by Reference to a Master Standard

The young lady in the right foreground of this slide is seen ready to read the standard, but is waiting while the operator is making some adjustment, for which purpose he has removed the front cover of the instrument. When tested each calibrated mark is carefully checked, and unless it agrees with the indications of the standard the scale is remade.

Slide No. 522
Adjusting by Reference to a Wheatstone Bridge

In the preceding operations of adjusting, calibrating and checking, the actual resistance required was obtained by first inserting a rheostat in series, but as the instrument must be specifically adjusted with all of its ranges self-contained, the next operation is that of determining the exact resistances of these ranges and preparing coils, sheets, etc., of suitable ohmic value that can be permanently connected in the instrument as fixed resistors.

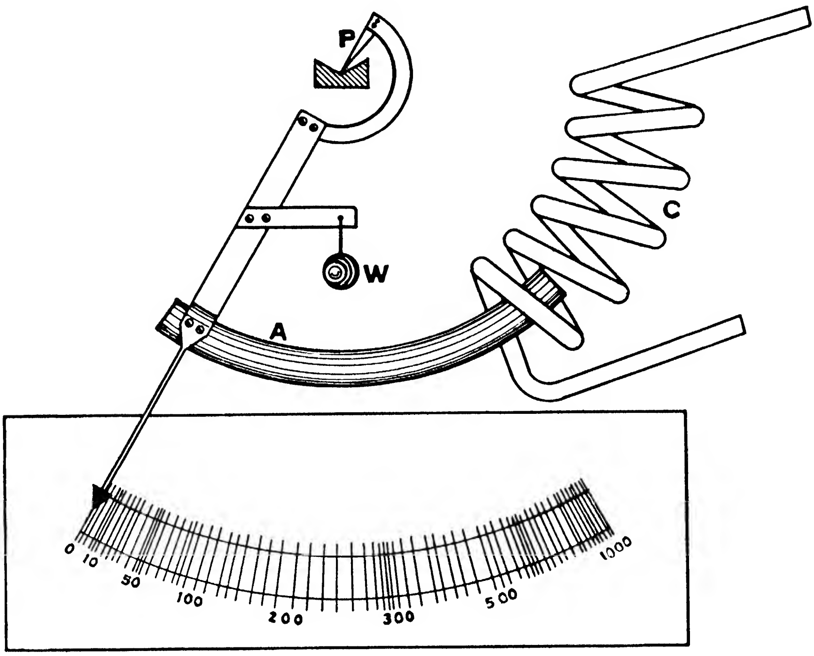
Of course, the nature of these adjustments depends upon the type of instrument and the purpose for which it is intended. A voltmeter, for instance, should have a very high series resistance in ohms per volt, so that the current required to operate it will be very small when it is connected across the potential of the circuit; and on the other hand, the resistance of the ammeter should be as low as permissible as it is always connected in the path of, or in series with the circuit being measured—but ammeters are actually shunted millivoltmeters, for which reason they will be considered separately.*

* A full description of Weston instruments, and the principles involved in their design and operation, will be found in Weston Monographs "B2" and "B4," to which we refer the instructor who desires to enlarge on what we offer herein.

Slide No. 523
Inspecting Instruments

At every mechanical and electrical stage in the assembling, calibration, final polishing and finishing of an instrument, inspection is necessary. In this picture the inspector in one of our laboratories and one of his assistants are "looking for trouble." To do them justice, inspectors are always looking for what they prefer not to find, but nevertheless it is their duty to see that no instrument leaves the laboratory either for sale or for stock if it has any defect in materials, adjustment or finish. One of the last operations performed by inspectors, after the case and seals are in place, is to run the pointer over the scale once more to see that the movable coil is operating properly. In this picture the chief inspector to the right is examining the movable system of an alternating current ammeter, and his assistant is inspecting a double scale direct current volt-ammeter made specially for automobile dashboards.

## CURRENT INDICATORS AND SHUNTED CIRCUITS

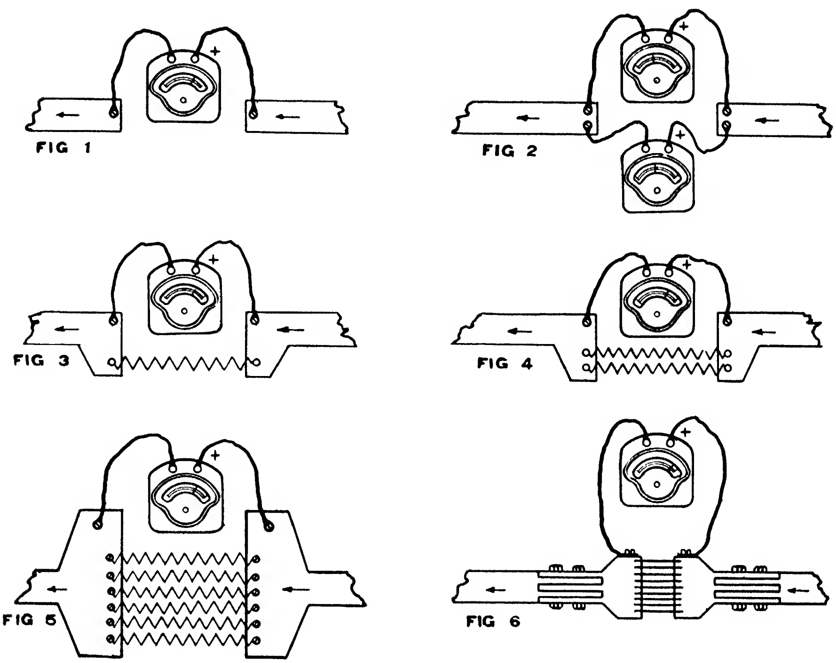



Slide No. 524
A Solenoidal Meter, Gravity Control

The development of the dynamo for producing large currents created an immediate demand for an apparatus by means of which such currents could be measured. It was natural that most inventors should attempt to construct current indicators based upon the scheme of using a solenoid carrying the entire load.

In this connection we find it convenient to borrow an illustration and a description from a popular text book * as follows: "A simple arrangement (Slide No. 524) is often used as an ammeter when a cheap instrument for rough measurement is required. The current flowing through the low resistance coil C, sucks the soft iron plunger A, pivoted at P, up into the coil. This causes the pointer to move over a scale which is calibrated by sending known currents through the coil C. The control is effected by means of the weight W, called a 'gravity' control, and damping is accomplished by means of the eddy currents in the plunger A. Neither the damping nor the control is good, due to the comparatively large masses of the moving parts, the large amount of inertia and the friction on the pivot. Moreover, an instrument of this type has large errors, owing to hysteresis or lag, due to the excessive mass of its movable iron parts."

* "Elements of Electricity," Timbie.




Slide No. 525
Divided Circuits and the Evolution of the Weston Shunt

A much better plan than using a solenoid, or in fact, any device which is operated by sending the entire current through it, is to divide the current and construct the instrument in such a way that it carries only a small part of the total current. For instance, in Slide No. 525, Fig. 1, the only path for the current is through the instrument. Suppose we did not know whether this current amounted to less than 1 ampere or over 100 amperes, and the instrument was of single range, and intended to carry not over 1 ampere; then it would not be safe to throw on the full load. On the contrary, we would be obliged to increase it gradually, and if we found that it was greater than 1 ampere, we could divide it up by using another instrument in multiple with the first, as shown in Fig. 2, and their readings added together would, of course, give the total current. We could employ three or more instruments in this manner, but this would be a clumsy and expensive method.

The best arrangement is obtained by the introduction of a shunt in the circuit.

If we look up the definition of the word "shunt" we will find that in England it originally meant a sidetrack for turning off a car or train from the main track. It is what we call a "switch," particularly one which branches off from the main road and joins it again farther on.

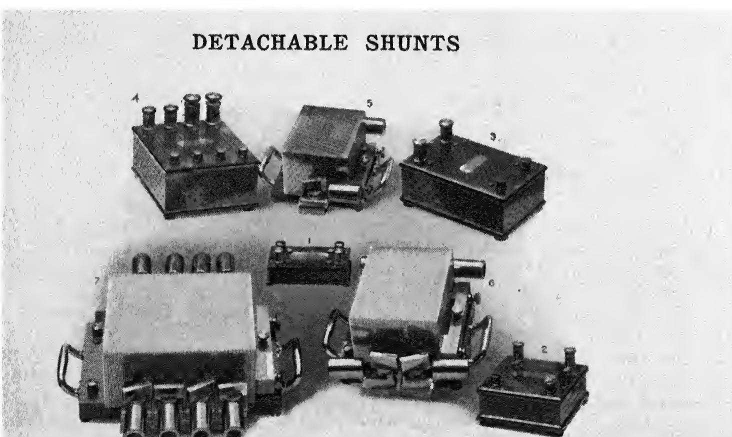
An electrical shunt is in a sense similar to a railroad shunt, since it is used to sidetrack part of the current flowing through a conductor. To fully understand the object and principle of shunts for current indicators, it is only necessary to study Fig. 3. Here we have only one instrument and a resistor or shunt which we have adjusted so that its resistance is equal to that of the instrument; then, of course, half of the current will go through

this shunt, and all we have to do is to multiply the indication of the instrument by 2 to determine the total current.

If we carried this scheme further and added another shunt, as in Fig. 4, it follows that (the three circuits being alike) the instrument indication would represent 1/3 of the total current.

We might continue in this manner indefinitely, adding any number of shunts (Fig. 5), adjusted so that each one had the same resistance, but why should we use such a clumsy method when all that is necessary is to consider all of these shunts as a unit and determine its resistance as a unit, no matter how many separate conductors it may be made of. It will not affect the result if these are not alike in size or resistance, provided each has sufficient dimensions to carry its share of the current; and if we firmly solder all of them to a suitable block, and provide terminals for fastening the instrument, then, instead of having a number of individual shunts, we have a single multiple blade shunt (Fig. 6). And if we find that the total shunt resistance is 1/2, 1/10, 1/100, 1/1000 or any other fraction of the instrument resistance, is it not easy to decide what part of the total current will flow through the instrument and calculate what the total current actually will be?

Or, to be in accord with these time-saving, labor-saving days, suppose the manufacturer does the calculating for you, once and for all and puts the shunt inside of the instrument or makes it detachable—as you prefer—and calibrates the scale so that it will correctly indicate the total current? Why, then, you have a Weston direct-current ammeter.*




Slide No. 526

Alloy Shunts for Portable and Laboratory Standard Instruments

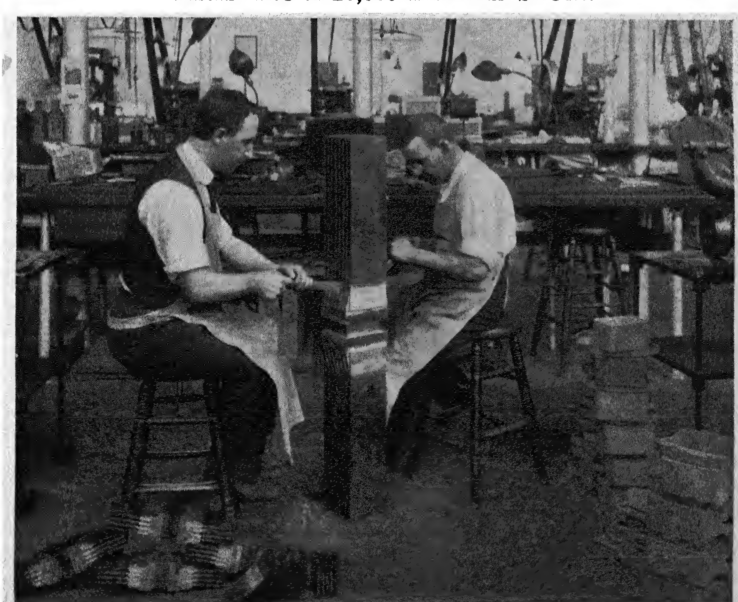
1. 0 to 3 amperes inclusive
2. 4 to 75 amperes inclusive. (In ranges 4 to 40 amperes slightly smaller shunts of the same style are used.)
3. 100 to 300 amperes inclusive
4. 3 ranges up to total capacity, 300 amperes
5. 400 to 500 amperes inclusive
6. 700 to 1500 amperes inclusive. (Ranges for 1200, 1400 and 1500 amperes are slightly larger than the others, having 3 terminals on each side.)
7. 2000 amperes.

* To simplify this demonstration we have used an instrument of one ampere range as a basis. But the student should not be permitted to assume that for this reason a current as large as one ampere is required for a Weston movable system. In the actual construction the current flowing through the coil and springs is seldom more than 0.03 ampere, this being sufficient for a full scale deflection.

The current which a shunt has to carry is what chiefly determines its size, because it is evident that enough metal must be used to prevent the shunt from becoming overheated; and at the same time the resistance must be high enough to permit a suitable portion of the current to flow through the movable coil of the instrument, and although the temperature of the shunt may be raised by the current, the resistance of the shunt must not increase appreciably in order that the results obtained may be correct within a wide range of temperature. To accomplish this special alloys are used, belonging to a group invented by Edward Weston and known as manganin, or as Weston alloy, according to their constituents and proportions.

When the current is very great it is not practical to construct an instrument with a self-contained shunt because the instrument itself would become so large as to be unwieldy; and besides, the path of the current conductors would have to be more or less indirect in order to reach the instrument. It is much more convenient, therefore, to construct the shunt separately, provide it with suitable terminals and connections and insert it by cutting the main conductors (or bus bars as they are called) at any convenient place. The indicating instrument is then connected with the shunt by means of flexible leads, which are measured and adjusted so as to form part of the instrument circuit.

## FINISHING A 20,000 AMPERE SHUNT



Slide No. 527
Trimming a Switchboard Shunt

The shunt now illustrated is one designed to have a capacity of 20,000 amperes. It is being given some finishing touches before its final electrical adjustment.

## SWITCHBOARD SHUNTS


Slide No. 528

Shunts for Switchboard Ammeters

1. from 25 to 200 amperes
2. from 250 to 400 amperes
3. from 500 to 600 amperes
4. from 600 to 800 amperes
5. from 1000 to 1200 amperes
6. from 1500 to 2500 amperes
7. from 3000 to 4000 amperes
8. from 4000 to 4500 amperes
9. from 4500 to 6000 amperes

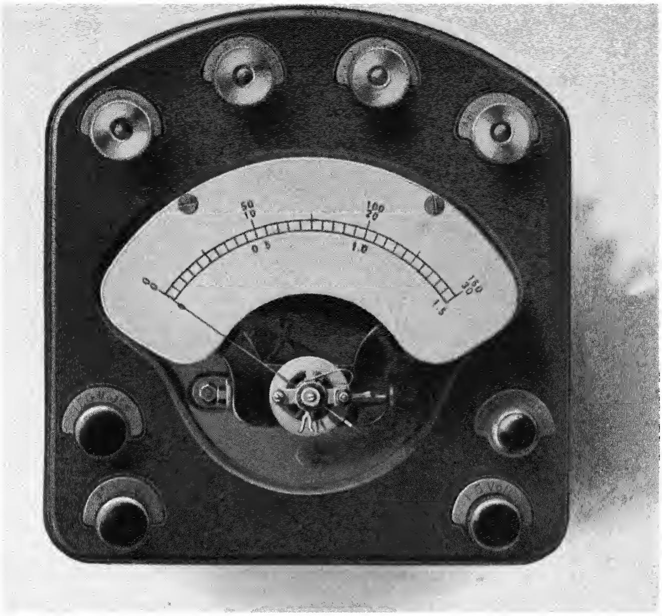
The general appearance of switchboard shunts for various ranges is shown in this illustration. The ampere capacity of these shunts is from 1 to about 10,000 amperes. You notice, of course, that Weston shunts are built of a number of blades with spaces between them. This construction is adopted to permit ventilation. Practical considerations, such as space required, quantity of materials and consequent first cost, make it desirable to reduce the dimensions of shunts as much as is feasible. The heating effect of a current is necessarily manifested chiefly on the surface of conductors, hence it is evident that the greater the surface exposed to radiation, the greater will be the current carrying capacity of the shunt as a whole; or inversely, for a shunt of definite maximum carrying capacity, less material will be required if a shunt is laminated than when it is composed of one solid conductor.

One of the most important advantages of the separate or detachable shunt is due to the fact that it may be placed directly in the line on the bus-bars of a switchboard, without changing their path or adding to their length. This saves materials and promotes economical distribution of current.

At the same time the indicating instrument may be mounted wherever it is convenient to have it; and where it will be uninfluenced by the effect of extremely heavy currents.

## A COMBINED VOLTMETER AND AMMETER

To suit certain purposes instruments of the Weston movable coil type are arranged so that the same instrument may be used either as a voltmeter or as an ammeter, and successive readings of voltage and current may be made with great rapidity.



Slide No. 529

Model 280 Volt-Ammeter with Cover Removed

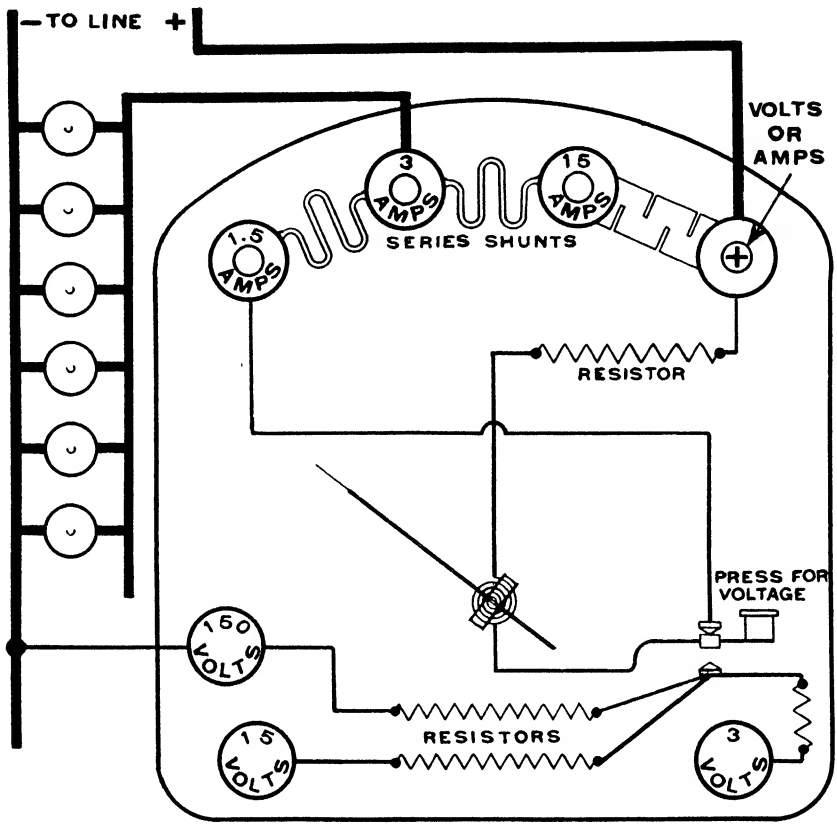
The instrument now shown is of triple range for both voltage and current, usually adjusted for a maximum voltage of 150 volts, with sub-ranges for 15 and 3 volts. The ampere ranges are usually 30, 15 and 3, or 15, 3 and 1.5 as preferred. Many other combinations are obtainable.

In order to obtain a clear idea of the general scheme of one of these instruments, it is desirable to show a second picture in the form of a connection diagram. You will notice that the shunts are in series with each other, and are connected in multiple with the movable coil through a resistor and a press button. When connected in the line only a small part of the current flows through the movable coil, but the pointer indicates the **total current,** because the current flowing through the movable coil is always in exact proportion to the total current, and, therefore, the scale is calibrated to indicate this total current.

If the proper voltage range is connected across the line and the button is pressed, the main current continues to flow through the shunts, but the pointer no longer indicates amperes because the movable coil circuit to the shunts is opened; and when the button is fully depressed the movable coil will form part of the voltage circuit.

Since a correctly adjusted non-inductive resistor is connected with each voltage range, the one in use will indicate volts, because the current which will flow depends upon the voltage of the circuit. This instrument may, therefore, be used to give volt and ampere indications in practically instantaneous succession as the button is pressed and released.

And now a resumé is in order, because this instrument may be used to demonstrate all of the fundamental principles we have already referred to, as well as many others. Let us see how:




Slide No. 530
Diagram of Weston D.C. Model 280 Volt-Ammeter

Galvani's discovery is necessarily applied because the instrument is operated by means of "galvanic" electricity instead of "static."

Oersted's experiments and Ampère's laws are shown by the fact that the movable coil is attracted by a magnet when current is flowing.

Volta's discovery is emphasized when we consider that the deflection of the movable coil is due to electrical pressure or voltage, and the greater the voltage, the greater the deflection.

Schweigger's experiment is illustrated by reference to the winding of the movable coil, which has several turns, instead of only one as originally formed by Ampère.

Faraday's and Henry's researches are exemplified in the application of an intense magnetic field and the utilization of a permanent magnet.

Arago's discovery is taken advantage of as a means for slowing down or damping the motion of the movable coil. This is accomplished by winding the movable coil upon an aluminum frame. Eddy currents are formed in this frame when in motion because it cuts the lines of force of the magnet.

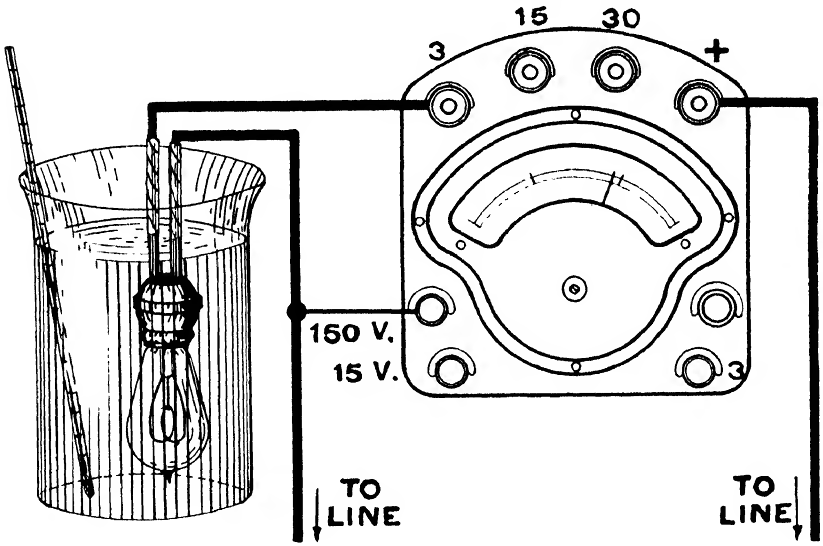
Moll found out that a current would flow freely through a conductor of large size, and was reduced when forced to flow through a fine wire.

What puzzled him could be easily explained by reference to the quantity of current which will flow through the shunts, as compared with the amount flowing through the movable coil and series resistors, when the voltage applied is the same in both cases.

It is hardly necessary to state that the laws of Ohm are demonstrated by the fact that the quantity of current which will flow through the instrument depends upon electromotive force and resistance.

And finally, even static effects may be shown in clear, cold weather, and the principle of Coulomb's and Henley's electrometers illustrated. To do this, rub the scale glass with a dry cloth or tissue paper. The surface thereby receives a static charge, and the pointer is attracted. Incidentally, to get rid of any residual charge you have merely to breathe upon the glass, which will dissipate it.

## THE HEATING EFFECT OF AN ELECTRIC CURRENT




Slide No. 531
Weston Model 280, Used as an Ammeter and Voltmeter

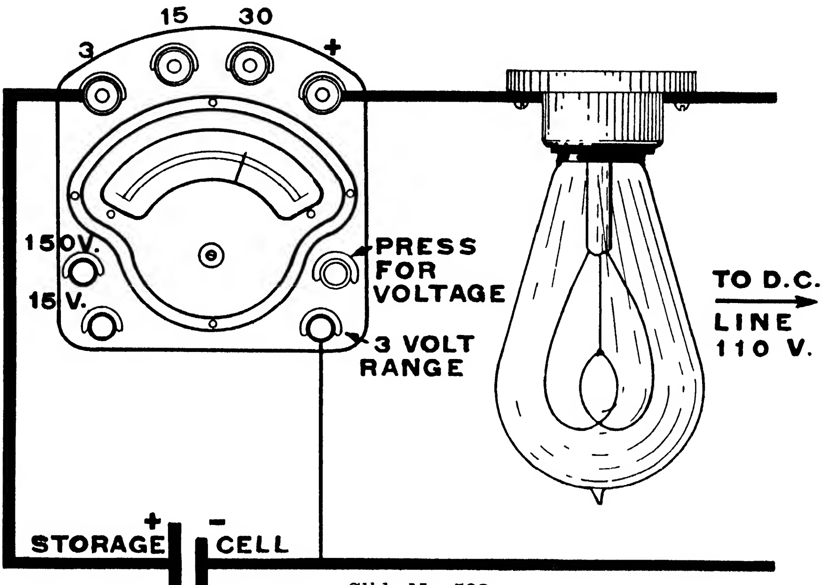
In several text-books, as well as in the Weston Monographs, numerous practical experiments will be found performed with a direct current from a service line; and intended to show the heating effect of a current. Among these may be mentioned the determination of the number of British thermal units per second under given conditions, efficiency tests of domestic electrical apparatus, etc. These experiments were almost invariably performed by using a separate voltmeter and ammeter, or else a double scale instrument. Only one instrument is necessary if it is a double range Weston model 280 volt-ammeter.

The slide now being displayed merely gives a practical illustration of the method of making connections in such experiments, the ranges selected, of course, depending upon the conditions.

Two students may work together on an experiment of this kind, and if the mean of a number of observations is required, they can alternately note the voltage and current indications at regular intervals, without the slightest trouble or interference.

EXPERIMENT No. 1

# CHARGING A STORAGE CELL FROM A SERVICE LINE




Slide No. 532

Charging a Storage Cell from a D.C. Service Line

A storage cell may be charged from a direct current service line with a lamp, or bank of lamps, in series to limit the amount of current flowing. In order to be able to properly regulate the current an ammeter is necessary, and if a single cell is being charged a Model 280 volt-ammeter may be employed, and its 3-volt range connected as shown. It looks risky at first glance, but it is quite safe, provided the connections are secure.

However, it might seem that pressing the button should result in burning out the 3-volt range by short-circuiting it across the 110-volt line, but this is not the case.

The following tests may be made with ease and rapidity:

The current **input** will be normally indicated by the pointer, its amount depending upon the line voltage and upon the resistance (or load ballast) in the circuit.

The charging voltage that is required to overcome the e.m.f. of the storage cell may be determined by pressing the button and noting the deflection obtained.

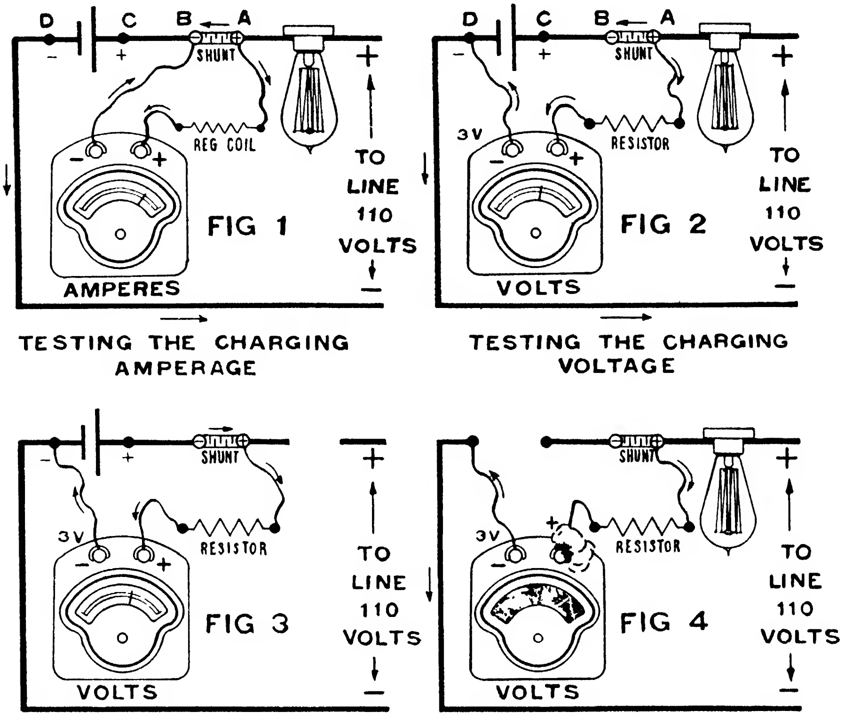
The discharge voltage of the storage cell may be tested by removing or unscrewing the lamp and then pressing the button.

The ampere-hour charge or watt-hour input can be calculated by noting the total time, the average current and the charging voltage.

The cost of charging the cell may be calculated by using the average line voltage as a constant, in place of the charging voltage, and applying kw. hr. service rate.

**CAUTION.**—Connections must be secure. To prevent accidents the cell voltage should be tested after the wiring is completed, and before the lamp is screwed in.

## AN ANALYSIS OF THE CELL CHARGING METHOD




TESTING THE CHARGING AMPERAGE

TESTING THE CHARGING VOLTAGE

TESTING THE DISCHARGE VOLTAGE

BURNING OUT THE MOVEMENT

Slide No. 533

Analysis of the Operation of a Weston Volt-Ammeter, When Used in Charging a Storage Cell

In order fully to understand the operation of the volt-ammeter as used in the preceding test, let us substitute a single range instrument containing only a scale and movable system connected directly with the binding posts. Then if we connect a shunt in the line, as in Slide No. 533, Fig. 1, we can use the instrument as an ammeter, if we add a little regulating coil and adjust it until the instrument is correct. Under these conditions it will indicate the charging current flowing through the lamp, shunt and storage cell.

In Fig. 2 we have connected a resistor in series with the movable coil, and adjusted it so that the instrument may now be used as a voltmeter. You will notice that the minus binding post of the instrument has been connected to D, so as to include the cell.

The current now passing through the instrument is equal to the potential difference between D and A, divided by the resistance of the movable coil and resistor.

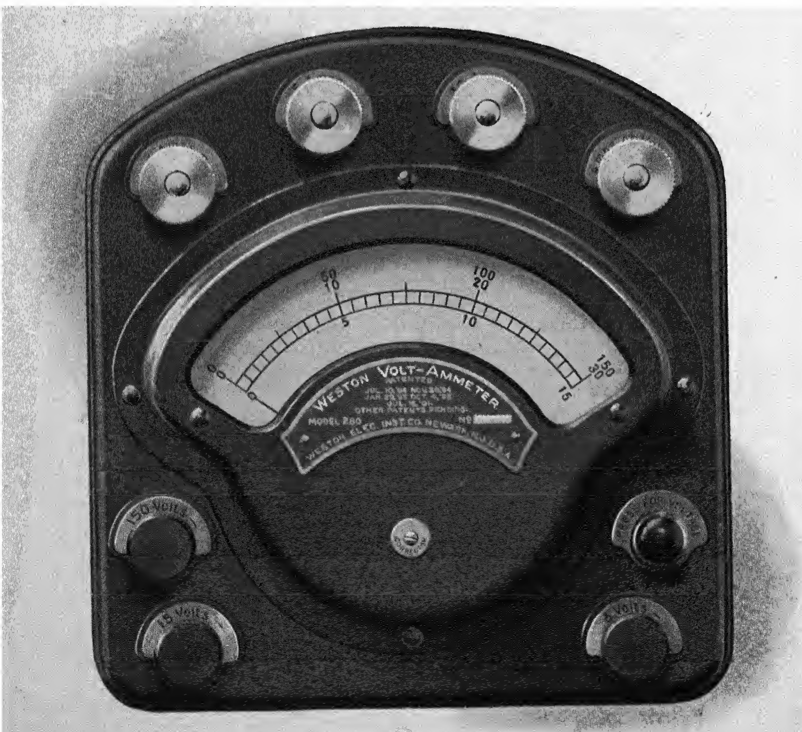
In Fig. 3 we have removed the lamp, thereby breaking the charging circuit; but the instrument remains connected across the shunt and storage cell. A very small current from the latter will now flow through the shunt in the direction of the arrows, and through the instrument, which latter will show the open circuit voltage or e.m.f. of the cell. The shunt becomes

merely line resistance, and since the instrument has a resistance of sixty or more ohms per volt, the resistance of the shunt will not introduce any observable error.

Finally note Fig. 4. The lamp has been replaced and then somebody who should have known better has removed the storage cell. The result was disastrous, because the only remaining path for the current was through the instrument itself, and since the 3-volt range was connected across a 110-volt circuit, enough current was caused to flow through the movable coil to burn it out.

## A BURN-OUT, DUE TO INCORRECT TEACHING

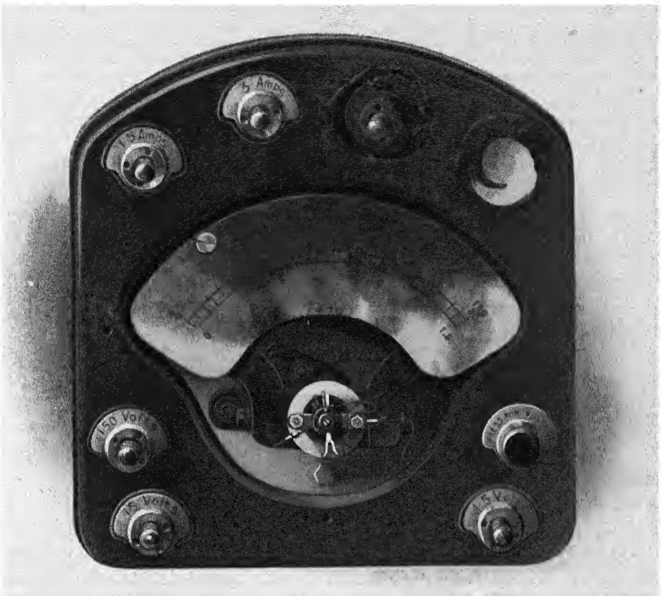
And now, having shown that the legitimate use of a Model 280 may be greatly extended by giving a little consideration to proper connections, we will go to the other extreme, and illustrate how much damage can be done in a few moments by misuse. But first let us take a glimpse at one of the best and most serviceable instruments ever produced. This is the Model 280 triple range, complete and perfect. Its development in brief was as follows: The movable system, iron shield and magnet were originally designed for automobile service, and instruments for that purpose embodying these parts are made and are known as Models 267 and 268. They are installed on the dashboard and indicate the current and voltage of the battery used on self-starters and on lighting systems. Necessarily such an instrument had to be designed to withstand the severest strains and vibrations.




Slide No. 534
A Perfect Instrument

It occurred to us that a modification of the automobile instrument would serve excellently for general use as a voltmeter or ammeter. It was accordingly remodeled, provided with a special pointer, scale, base, shunts and binding posts, and refined in details; but the sturdy characteristics of the original movable system were retained.

Shunts for these instruments have a safe overload capacity of 50%, and can be overloaded 100% for a short time before they will fuse.



Slide No. 535
A Wreck—Burned-Out Model No. 280

But nothing that human ingenuity can produce is indestructible; and this (Slide No. 535) is what remained of one of these beautiful instruments, after its 30 ampere range had been short-circuited across the terminals of a large storage battery.

Note that the insulating material under the 3 and 1.5 ampere binding posts is in good condition, whereas at the 30 ampere binding posts the insulation has not only been destroyed, but, in addition, the iron base has been fused around the shunt terminals.

Part of the current necessarily passed through the movable coil, burning the insulation before the conducting springs flashed and opened that part of the circuit.

The instrument must have been burned out very quickly because the metal base was fused around the binding posts, and yet the heat did not have time to spread and raise the temperature of the base as a whole to any great extent, as shown by the condition of the remaining parts.

A piece of fuse-wire, two inches long and costing less than one cent, would have made this accident impossible. **THERE IS A MORAL IN THIS!**

The high-school student who ruined this instrument was taking a post-graduate course before entering college. He excused himself on the ground that he had been taught to "test" ordinary cells by short-circuiting them across an ammeter, and thought that this was a proper method. Therefore, he used it to "test" the ampere capacity of the storage battery!

Of course, he should have been taught that an ammeter is intended to measure current, and that this current will depend (See our friend, Ohm, once more): (1) Upon the voltage and (2) upon the resistance of the circuit. Now the resistance of a Weston ammeter is **low;** and when the external circuit consists of nothing but an ammeter and short heavy connecting leads, it follows that the total resistance of the circuit depends largely upon the resistance of the cell or battery from which the current flows.

A new "dry cell' will often have so low a resistance that it will give as much as 30 amperes on short circuit, and a storage cell, even if small, may give 100 or more amperes on "dead" short circuit.* Therefore, a student should be provided with a suitable rheostat or lamp bank when attempting to use an ammeter to determine the internal resistance, current output, or polarization of a commercial cell or battery of any type, and instructed to gradually decrease his external resistance while observing the indications of the ammeter.

Many text books and laboratory manuals, we regret to state, advise connecting a cell directly with the binding posts of an ammeter; and in some exercises even state that if the current is too large for the instrument, a resistor may then be added. This is both bad teaching and bad practice.

These books advocate a destructive method which is very often based on a bad "guess" as to how much abuse an instrument can withstand, but if somebody threw the authors of these books overboard to find out if they could swim, or pointed a gun at them, and pressed the trigger to find out if it was loaded, they would be indignant at such deadly folly.

If it is really important that students should study the resistance of cells, then pound this into them:

**A MODERN CELL, BE IT STORAGE OR PRIMARY, IF IN GOOD CONDITION, HAS A RESISTANCE WHICH IS VERY LOW; AND THE LOWER THIS RESISTANCE IS, THE GREATER THE CURRENT WILL BE ON SHORT CIRCUIT. THEREFORE, BEGIN YOUR EXPERIMENT BY ASSUMING THAT YOUR CELL IS IN EXCELLENT CONDITION; THAT CONSEQUENTLY ITS RESISTANCE IS PRACTICALLY ZERO; AND ITS CURRENT WOULD BE INFINITE, AND TAKE PRECAUTIONS ACCORDINGLY.**

And above all, give students a fuse of such size or capacity that it will "blow" before the ampere range in use can be overloaded.*2 If this fuse is of bare wire it should **not** be connected directly to an instrument binding-post; and should be enclosed or else be placed in a part of the circuit where it cannot do injury to the experimenter if it blows unexpectedly.

Remember, a blow from a bare fuse is like a blow from a bare fist, very bad for the eyes unless you protect yourself.

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* See article on "The Action of a Simple Cell," in Monograph "B2."

*2 See Experiments Nos. 4 and 5 in Monograph "B4."

# A STUDY OF PRIMARY CELLS

## POLARIZATION, INTERNAL RESISTANCE AND CURRENT CAPACITY OF PRIMARY CELLS

BY

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THESE subjects, when in the form of exercises and laboratory experiments, should be subdivided and form the basis for several separate, but inter-dependent studies. The attempt to overcome the effect of polarization upon the current strength and voltage of a cell has given us the many varied types of cells now on the market. This multiplicity of primary cells frequently leads authors of text books to devote considerable space to their description, with the result that few students acquire a definite understanding of even a few of the characteristic types.

In spite of the fact that the dynamo has supplanted the primary cell in many instances (telephone, telegraph, railway signal work, etc.), the latter has still a wide field of usefulness. It also remains a very desirable piece of apparatus in the teaching of such fundamentals as current, electromotive force, resistance, specific conductivity, etc.

In the study of the construction and operation of bells, telegraphs, telephones, etc., as carried on in the average high school laboratory, the primary cell is the source of energy most frequently used. If the student can be taught to exercise proper care in the use of primary cells under the above conditions he will have acquired fundamentals relating to circuits which will prove valuable when dealing with connections employing higher voltages.

If also we remember that the accepted international standard for the determination of the unit of electromotive force is a primary cell, which, while amazingly constant with proper usage, can be practically ruined by short-circuiting, we realize that the study of cells cannot with propriety be ignored.

Without undue trespassing upon the domain of our friend and co-worker, the instructor in chemistry, we may also impart a few elementary facts relating to the constitutents of modern cells, and the difference in their chemical action; so that the beginner may at least know that a "storage" battery does not store electricity and that a "dry" cell is not dry. The equation for the zinc-copper sulphuric acid cell can be taught in connection with the discussion of a simple voltaic cell. An explanation of the ill effects produced by the free hydrogen in this equation leads to the outlining of the various methods employed in the elimination of this evil, and to the introduction of such types of cells as: Dry, Leclanche, Gravity and Porous Cup Daniell. In the Dry and Leclanche cells a limited amount of hydrogen can be taken care of; in the Gravity and Porous Cup Daniell cells polarization is entirely eliminated, the chemistry of which can clearly be shown by the addition of one more equation to that of the simple cell.

Current, and the chemical action upon which current depends, should no doubt be given precedence; and yet polarization as a usual concomitant, and increased internal resistance as a result, are so closely related that a clear conception of all three is as necessary, for a proper understanding of the subject, as familiarity with the fundamentals of Ohm's Law.

In the study of cells it is questionable if very much time should be given to the effects of grouping in series, parallel or series-parallel. Series connections are, of course, of great importance in the study of e.m.f., while a clear conception of the effects of multiple grouping can be imparted by emphasizing the fact that multiple connections merely serve to increase the output by enlarging the dimensions of the elements; that for instance, all the

zincs could be cast together, and the carbon or copper plates be made of one piece; and that one jar or vessel of suitable size could take the place of the individual receptacles. And then, by way of contrast the necessity for good insulation in series connection should be explained, and perhaps a demonstration given of the effect on the e.m.f. if two cells are first connected in series and then connected in parallel or combined by putting two sets of elements into one jar.

Another problem is the degree of importance which should be attached to the probable output of cells and the resultant effects. For instance, as a general proposition it may be stated that the e.m.f. of any modern primary cell in good condition is almost invariably between 0.8 and 1.5 volts. The current capacity of cells depends, however, upon their size and materials, and there is such an enormous difference in this respect that it is necessary to emphasize the fact. For instance, a Daniell or a Gravity cell under the most favorable conditions will not yield more than about 0.5 ampere on short circuit, whereas a dry cell may give over 30 amperes when new. A much needed lesson, therefore, is one by which the student may freely understand when short-circuits are permissible and, where a cell is an unknown quantity, to learn when to be on the lookout for trouble. This is especially the case when instruments having definite limited ranges are employed for testing purposes.

This brings up the question whether safety devices should be insisted upon in connection with the use of valuable apparatus when placed in the hands of a beginner. Of course, we would look askance at a small steam boiler for experimental purposes which was unprovided with a safety valve, and hence with equal reason we might claim that we should endeavor to prevent electrical blow-outs as well as mechanical blow-ups. Safety devices for the protection of valuable electrical apparatus are one of the most important considerations in the equipping and installing of modern electrical power plants. A student in making generator or transformer tests or other experiments of a like nature would undoubtedly be required to have his circuit properly protected by means of fuses, circuit breakers or other safety devices. It would seem that the value and purpose, and above all the necessity of proper protective devices, should be instilled into the student's mind from the very first experiment that may call for such protection. The most experienced and most careful experimenter cannot afford to consider himself free from the dangers arising from wrong connections or accidental short-circuits. How much more so is this true of the beginner?

The proper study of fuses requires extensive experimenting, and is really a separate subject which can be taught to the best advantage in connection with a power plant or service line; but the fact that a fuse can be blown by a single cell is in itself impressive and instructive.

It is possible to have the student construct fuses for experimental purposes at practically nominal cost, as follows:

Tin foil, of the kind used in the manufacture of condensers can be obtained in sheets of various sizes and thickness. The thinnest is usually about .0005 inch. If a piece of this foil is mounted on a sheet of writing paper by means of photographer's paste, and flattened in a book or press, it may be cut into strips and will make excellent fuses.*

Its special advantage lies in the fact, that, after a few experiments, its carrying capacity can be estimated with a fair degree of accuracy. For instance, experiments will show the following results:

| Thickness | Width | Fusing Point |
|---|---|---|
| .0005″ | $\frac{1}{16}$″ | 1.2 amps. |
| .0005″ | $\frac{1}{8}$″ | 3.0 amps. |
| .0005″ | $\frac{1}{4}$″ | 6.5 amps. |

* Fuses constructed in this manner are of practical value in connection with the operation of an oscillograph. Gold foil fuses mounted on paper are employed.

Of course the length of the strip is to some extent a factor, as well as the thickness of the paper. For example, a 1/8-inch fuse will blow at 2.25 amps. when the paper is removed. But while there may be irregularity in the results obtained, there is no doubt about the approximate capacity and the utility of these fuses as safety devices.

Another interesting feature when these fuses are used on low potentials is the effect of their length, or to be more exact, the introduction of resistance due to their length. For instance, with bridge measurements, the following results have been obtained at room temperature:

| Temperature | Length | Width | Resistance |
|---|---|---|---|
| 18° C. | 6″ | ¼″ | 0.37 ohm |
| 18° C. | 6″ | ⅛″ | 0.74 ohm |
| 18° C. | 6″ | $\frac{1}{16}$″ | 1.50 ohms |

From these results it can be seen that, if a dry cell which will yield 30 amperes on short-circuit and which would damage the instrument if directly short-circuited, is connected to the 1-ampere range of an ammeter in series with a 6-inch strip of foil, 1/16 inch wide, and .0005 inch thick, the effect will be that the foil will either act as a safety device by blowing, or if it carries the current, its own resistance will be sufficient to limit the flow of current to approximately 1 ampere.

In performing the experiments on "Capacity of Tin Foil Fuses," "Polarization" and the "Daniell Cell," the student in the Electrical Department of the Buffalo Technical High School is required to follow an outline which is used in all experiments and which is arranged as shown by the captions in the exercises following.

Before the student begins any experiment he is given instruction upon matters that may come up under the various headings in the outline.

The "Object" with, in some cases, its sub-divisions, is clearly stated and the student makes an exact copy of the same.

Under the heading of "Apparatus" a complete list of all necessary materials, instruments, etc., is given so that the experimenter may call upon the stockroom keeper for all the equipment needed for his particular experiment.

Full "Connections" are clearly drawn out for the student and he is not only required to make a sketch of them and carefully follow the same in the laboratory, but it is insisted upon that no circuit be made alive until the connections have been checked by the instructor, in order to see that the instructions given under this heading have been strictly adhered to. Standard symbols are used in all diagrams of connections whenever possible.

"Observations" are required to be neatly tabulated and of such nature and values as called for in the "Object" of the experiment.

"Calculations" are made by the use of the values secured under the heading of "Observations."

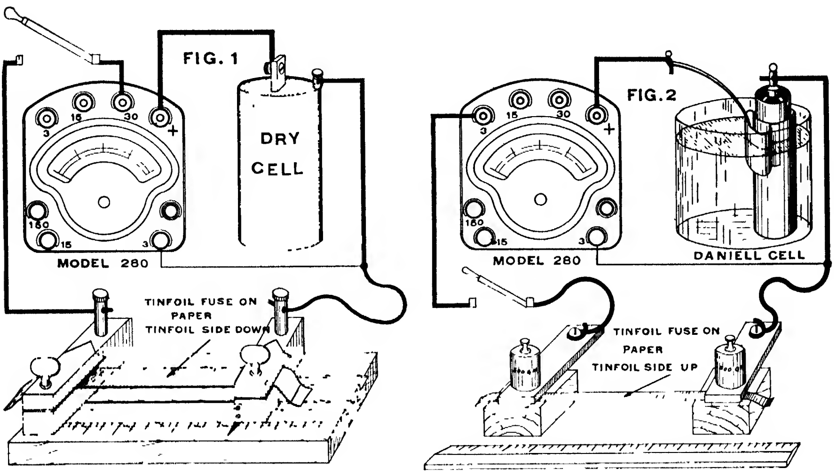
In the "Description" a complete discussion of the method employed in securing the observations and in getting the results asked for in the observations is given. This discussion is a ready means by which the instructor can determine whether or not the student performed the experiment according to directions and whether the experiment is properly understood.

The "Conclusion" refers directly to the objects given in the experiments and should follow logically from the data secured.

The instructions given in connection with the three experiments that follow can be readily deduced by the reading of the descriptions under each experiment.

EXPERIMENT No. 2

# CAPACITY OF TIN FOIL FUSES




Slide No. 536

Testing Tin Foil Fuses with Primary Cells and a
Weston Portable Model 280 Volt-Ammeter

In the above method the cell is connected as shown in Figs. 1 or 2, so that its voltage may be determined whether the ampere circuit is open or closed. Wood blocks are used on which the fuse is laid with the tin foil side up, and held in place with metal blocks or weights. The distance between the blocks may be varied and noted with the aid of a scale, which also serves to measure the width.

## OBJECT

1st. To find the maximum current which will flow when a fuse and an ammeter are connected in series with a dry cell.

2nd. To find the maximum current which will flow when a fuse and an ammeter are connected in series with a porous cup Daniell Cell.

## APPARATUS

Columbia dry cell No. 6.
Porous cup Daniell cell.
Weston Model 280 volt-ammeter No. 5614.
Tin foil fuses.
Fuse block.

## CONNECTIONS

See Slide No. 536 (Fig. 2), reproduced from student's sketch.

## OBSERVATIONS

Table I

| Obs. | Width | Length | Blew | Amps. |
|---|---|---|---|---|
| 1 | 5/32″ | 2″ | Yes | 4.5 |
| 2 | ¼″ | 2″ | Yes | 6 |
| 3 | 5/16″ | 2″ | Yes | 7 |
| 4 | ⅜″ | 2″ | Yes | 7.5 |
| 5 | ½″ | 2″ | No | 8.5 |
| 6 | ⅝″ | 2″ | No | 9 |
| 7 | ¾″ | 2″ | No | 9.2 |
| 8 | 1 ″ | 2″ | No | 10 |

Table II

| Obs. | Width | Length | Blew | Amps |
|---|---|---|---|---|
| 1 | 1/32″ | 2″ | No | .36 |
| 2 | 1/16″ | 2″ | No | .45 |
| 3 | ⅛″ | 2″ | No | .5 |

## DESCRIPTION

In making this test and in securing the observations recorded in Table No. 1, I had a dry cell, an ammeter and a tin foil fuse mounted in a fuse block connected in series. The fuse block was used in order to protect the instrument from the damage that is done when fuses are connected to the binding posts of meters. The instrument used was a Model 280 Weston volt-ammeter having three ranges of current. The highest range 0-30 amperes was used in taking the first observation. It was seen from this observation that it was safe to use the next range, namely, 0-15 amperes. The width of the fuse was gradually increased until the maximum current flow was secured. I allowed the dry cell to be on closed circuit as short a time as possible in order that it be not weakened by polarization.

The observations in Table No. 2 I secured in the same manner as those in Table No. 1, except that a porous cup Daniell cell was used instead of the dry cell. The highest ampere range was used, and since I secured very little deflection I changed my connections to the middle range. The reading on this range showed me that I could use the lowest range 0-3 amperes without damaging the instrument, and this is the range that I used for all readings. The thickness of all fuses used in this test was .0005 inch.

## CONCLUSIONS

I conclude from the experiment:

1st. That a tin foil fuse 1 inch in width, 2 inches in length and having a thickness of .0005 inch will allow but 10 amperes to flow when connected in series with a Weston Model 280 volt-ammeter and a dry cell.

2nd. That a fuse ⅛ inch in width, 2 inches in length and having a thickness of .0005 inch will limit the current from a Daniell cell so as to protect the 0-3 ampere range of a Weston Model 280 volt-ammeter.

**PERFORMED BY:** CHARLES KLINCK.* Date: March 22, 1915.

* *"Performed by"* was originally under the title, but to clearly distinguish between matter prepared by instructors and students we have made it a practice to place the names of the former at the beginning, and of the latter at the end of their contributions.—COMPILER'S NOTE.

EXPERIMENT No. 3

# POLARIZATION AND RECUPERATION OF A DRY CELL

## OBJECT

1st. To observe the effects of a short-circuit upon the electromotive force and current capacity of a dry cell.

2nd. To observe the cell's recuperative power when left in open circuit.

3rd. To plot polarization and recuperation curves, using minutes as abscissae and amperes as ordinates.

## APPARATUS

Columbia No. 6 dry cell.
Weston Model 280 volt-ammeter No. 5614.
Tin foil fuse, 10 amperes.
Fuse block.
Connection wires.
Watch.

## CONNECTIONS

(See Slide No. 536, Fig. 1.)

## OBSERVATIONS

Polarization

| Obs. | Time | Amps. | Volts | Obs. | Time | Amps. | Volts |
|---|---|---|---|---|---|---|---|
| 1 | 11.05 | 10 | 1.39 | 12 | 11.15 | 5.9 | |
| 2 | 11.05½ | 8.25 | | 13 | 11.16 | 5.7 | |
| 3 | 11.06 | 7.8 | | 14 | 11.17 | 5.6 | |
| 4 | 11.07 | 7.6 | | 15 | 11.18 | 5.5 | |
| 5 | 11.08 | 7.25 | | 16 | 11.19 | 5.4 | |
| 6 | 11.09 | 7.00 | | 17 | 11.20 | 5.3 | |
| 7 | 11.10 | 6.8 | | 18 | 11.21 | 5.2 | |
| 8 | 11.11 | 6.6 | | 19 | 11.22 | 5.15 | |
| 9 | 11.12 | 6.35 | | 20 | 11.23 | 5.1 | |
| 10 | 11.13 | 6.15 | | 21 | 11.24 | 5.0 | |
| 11 | 11.14 | 6.00 | | 22 | 11.25 | 4.95 | .85 |

Note: Curves omitted owing to lack of space.

Recuperation

| Obs. | Time | Amps. | Volts | Obs. | Time | Amps. | Volts |
|---|---|---|---|---|---|---|---|
| 1 | 11.25 | 4.95 | .85 | 11 | 11.36 | 8.3 | |
| 2 | 11.26 | 7.0 | | 12 | 11.38 | 8.3 | |
| 3 | 11.27 | 7 2 | | 13 | 11.40 | 8.3 | |
| 4 | 11.28 | 7.6 | | 14 | 11.42 | 8.3 | |
| 5 | 11.29 | 7.8 | | 15 | 11.44 | 8.3 | |
| 6 | 11.30 | 8.0 | | 16 | 11.48 | 8.5 | |
| 7 | 11.31 | 8.0 | | 17 | 11.52 | 8.5 | |
| 8 | 11.32 | 8.1 | | 18 | 11.56 | 8.7 | |
| 9 | 11.33 | 8.2 | | 19 | 12.00 | 8.8 | |
| 10 | 11.34 | 8.2 | | 20 | 12.04 | 9.0 | 1.2 |

**DESCRIPTION**

I connected my dry cell as shown in the connections, using the 15-ampere range for current, and the 3-volt range for voltage. I pressed the button and took one reading of the instrument. By closing the series switch I connected my ammeter in series with the cell and left it connected thus until I had taken twenty-two readings at intervals of one minute each. At the end of the twenty-second ammeter reading I again took a voltmeter reading. After this voltmeter reading I took twenty ammeter readings, the first ten, one minute apart, the next five, two minutes apart and the last five, four minutes apart, the cell being left in open circuit between readings. I took one more voltmeter reading at the end of the ammeter readings.

**CONCLUSIONS**

1st. I conclude that when a dry cell is left in short-circuit it runs down very quickly, lowering both the current capacity and the electromotive force of the cell.

2nd. I conclude that as soon as a dry cell is left in open circuit, after having been short-circuited, it begins to regain its current capacity and electromotive force, due to the depolarizer $MNO_2$, which takes care of part of the polarization, but not enough of it to allow the dry cell to be used to good advantage in a closed circuit of low resistance.

PERFORMED BY: CHARLES KLINCK. Date: March 22, 1915.

EXPERIMENT No. 4

# CONSTRUCTING AND TESTING A DANIELL CELL

**OBJECT**

1st. To construct a porous cup Daniell cell.

2nd. To observe the effect of a short-circuit upon the voltage and current capacity of a Daniell cell.

3rd. To compare the readings with those secured in Experiment No. 3.

**APPARATUS**

Ampere stand.
Glass jar.
Porous cup.
Strip of copper.
Rod of zinc.
Dilute $H_2SO_4$.
Copper sulphate.
Watch.
Weston volt-ammeter Model 280. No. 5614.
Tin foil fuse, 1 ampere.
Fuse block.
Connection wires.

**DESCRIPTION**

I constructed the cell by placing the porous cup containing copper sulphate in the glass jar that I had partly filled with sulphuric acid. The porous cup I had previously placed in hot water for about five minutes in order to make the cup more porous. After constructing the cell I connected the volt-ammeter as shown in the connections.

By pressing the button I secured my first voltmeter reading. After I took this reading I closed the ammeter circuit. This circuit remained closed for twenty-two minutes, during which time I took twelve readings as shown in the observations. At the end of the twenty-two minutes I took another voltmeter reading.

**OBSERVATIONS**

| Obs. | Time | Amps. | Volts | Obs. | Time | Amps. | Volts |
|---|---|---|---|---|---|---|---|
| 1 | 2.30 | 0.5 | 1.03 | 7 | 2.36 | 0.5 | |
| 2 | 2.31 | 0.5 | | 8 | 2.38 | 0.5 | |
| 3 | 2.32 | 0.5 | | 9 | 2.40 | 0.5 | |
| 4 | 2.33 | 0.5 | | 10 | 2.44 | 0.5 | |
| 5 | 2.34 | 0.5 | | 11 | 2.48 | 0.5 | |
| 6 | 2.35 | 0.5 | | 12 | 2.52 | 0.5 | 1.03 |

**CONCLUSIONS**

I conclude from my observations that the current capacity and voltage of a Daniell cell are not weakened when the cell is left in a closed circuit.

**PERFORMED BY:** CHARLES KLINCK. Date: March 22, 1915.

# AN ELECTRIC STOVE

While attending the 1914 N. E. A. Convention in St. Paul, we learned through Mr. Frank H. Ball, Director of Industrial Education in Pittsburgh, that the construction of electrical stoves is part of the regular course in one of the schools in that city.

Since then we were informed that efficiency and cost of operation tests had been undertaken; and, therefore, corresponded with Mr. Ball and Mr. Howard L. Briggs, head of the Department of Electricity in the Irwin Avenue Industrial School, in order to obtain definite information relating to the entire project.

We quote from correspondence:

"GENTLEMEN:

"In line with Mr. Ball's ideas of 'practical projects for practical schools' I conceived the 'Toastove.' The idea of manufacturing the stove arose from the psychological necessity of a practical concrete project to arouse immediately the interests of the 'motor minded' boy in the more highly theoretical side of his trade.

"As the boys worked upon the problem the possibility of making it a project for the entire school became evident. Let me then name the various instructors and pupils responsible for the completed stoves used in these tests. First: Director Frank H. Ball, who put the hyphen in co-operation; Principal L. H. Turner, responsible for the name of the stove; Instructors, W. Whitely, V. Ververka, J. Stephenson and B. Zitzman, the boys of the latter printing our artistic little booklets.

"Last, but not least, Mr. M. Leon Haas, under whose instruction our design, difficult to construct of sheet metal, was successfully worked out into our sturdy toaster frames.

"Throughout construction the stove was used to illustrate various points of theory. Next came the tests of operation, which carries us to the Domestic Science Department of Miss H. Mates.

"In the efficiency and cost tests Weston Model 155 a. c. instruments were used, proving decidedly satisfactory.

"As to the real builders of the 'Toastove,' we must turn to the students, 'my boys,' Alexander and Wood, the boys who never knew 'Stuck' but learned 'Stick To It;' Cartwright and Piper of the same 'school' in the Sheet Metal Department; Patton and Behring, printers practical, and Miss Anna Barr, 'our cook.'

"Trusting the enclosed material will prove of interest, I remain,

"Respectfully,

(Signed) "H. L. BRIGGS."

## EXPERIMENT No. 5

# THE HISTORY OF THE "TOASTOVE"

Slide No. 537
Manufacturing a Toastove

"Our instructor of electricity suggested that Wood and I build an electric toaster.

"We decided that the first thing to do was to find out what the other fellow had already accomplished along this line. We studied the catalogues of the various makes and made a list of the best points of each. We then read up on heaters in 'Foster's Electrical Engineering Handbook.' We asked our instructor to explain all the points we didn't understand. We also made a list of the rules governing heating units in the 'National Electrical Code,' and made our plans comply with them.

"When we knew about what we wanted, our instructor gave us a charcoal sketch of the design he wanted worked out, from which we made a working plan, tracing it and making a blue print.

"We designed it to be as light, cheap, and as economical of operation as possible, and still be efficient and artistic.

"As cheapness of operation depends upon the full use of the heat generated, we figured out a good method of placing the heating element in this toaster so as to concentrate all the heat upon the object to be cooked.

"We looked up the subject of heating and found heat was given off in three different ways, by radiation, conduction and convection. We decided to enclose the heating element, as it was more sanitary and efficient; also to place a bed of heat-resisting materials on the bottom so that all the heat must travel upwards.

"We experimented about a week before we got a 'filler' for the toaster. Mr. Briggs said that it would have to stand up an hour under the blow torch without crumbling, and he would not accept anything we made until it would stand this test.

"We looked up the different makes of resistance wire and chose one particular type, as it was not too expensive and would not rust or become brittle under long service.

"We experimented upon several methods of placing this in the toaster and found ribbon wire to be the most efficient form, as we could use it in such a way that all the heat was applied immediately beneath the top. We also figured out the size and length of wire necessary.

"We selected from the catalogues the style of plug and cord we needed, and figured out the size of wire by using the tables and consulting the code.

"Our first intention was to have the stove made of cast iron, but our instructor thought it a good idea to have the whole stove manufactured in the school, and so he talked the plan over with the sheet metal instructor, who co-operated with us and who had his boys draw a sheet metal development. The first one was of sheet steel, the second of sheet copper, which made a much better stove.

"The latest improvement is an aluminum top, which will not tarnish, and makes a much better cooking surface.

"We got so interested in the first lot we turned out, that Wood and I worked from half-past twelve at noon until ten o'clock that night. We cooked supper on the first one we finished.

"The woodworking department made us a form for casting the channels, and the printing department is getting up our literature. I am writing this report in the academic department.

"We are making heat tests and plotting curves from them. One of the toasters which had been in use every day for two months was taken apart and found in the best condition.

"We are also getting up a shop system of manufacture so that we can make them faster.

"The heat resisting filler is cast in the pan by a wood form leaving channels in which the ribbon resistance is fastened.

"This is insulated from the top by a layer of mica. The ends of the ribbon are bolted by machine screws to the asbestos covered wire, coming up through the bottom in an insulated bushing.

"The top is then screwed on and the finished stove is buffed and lacquered.

"It was fun building the toaster as everybody 'pitched in' and helped us out.

"Mr. Ball, the Director of Industrial Education, sent away for samples of resistance wire and gave a lot of good suggestions. Our Principal, Mr. Turner, also took an active interest, suggesting that we change the name from 'Toasto-Stove' to 'The Toastove,' which made a much neater trade mark.

"Every teacher did what he could to encourage us.

"We had many failures at first, but our class motto is 'Stick To It,' and we won out.

"We think we have about as neat and as efficient a toaster as there is on the market. If it isn't, we want to know it, because we are going to keep at it until it is.

(Signed) "ROBERT ALEXANDER."

# DIRECTIONS FOR OPERATION OF THE "TOASTOVE"

"Electricity is being used more and more every day, and along every line. Now it is invading the field of cooking with the same rapid progress. Its cleanliness, uniformity of heat, rapidity, variety of uses and economy, all aid toward the increasing demand for electric cooking devices.

"The 'Toastove' is built in recognition of this demand, and is the result of careful investigation and experiment.

"The following points have been recognized:

"(1) The stove must be artistic in design so that it will go with any table setting.

"(2) It must be small and light.

"(3) It must have high efficiency.

"(4) It must be economical in operation.

"(5) One stove should fill all purposes.

"(6) To do this experiments have proven that three heats are necessary.

"(7) It must be built to wear and stand up under long service.

"(8) It must be perfectly safe and fireproof.

"There are three heats to select from. The high heat may be used when it is desired to heat anything quickly: soups, stews, water, etc. Then by turning to medium it will keep boiling, using the minimum of current. It will keep warm on low heat. The great economy of this can easily be seen.

"In frying, use high and medium. In broiling, high heat should be used. For toasting, use medium and low. For heating cold plates, etc., low heat should be used.

"In frying and boiling, a shallow pan with a tight cover will give the best results. For making scalloped oysters, puddings, broiling chops and steaks, the stove should be inverted over the top of the pan. For steak, use high heat. For puddings, etc., use medium and low.

"Toast, evenly and perfectly browned, is a better food than plain bread. The starch granules are changed to dextrine, and make an easily digested food. There is toast and toast, and toasters and toasters, but the nice, crispy golden brown obtained by our toaster cannot be equalled. The stove should be operated on second heat, using the wire grid to prevent burning.

"After finishing toast may be kept warm by operating on low heat.

"The 'Toastove' may be used for breakfast tables, teas, invalid's rooms, lunches, etc., offering a great variety of uses. It will answer all the purposes of a chafing dish with the proper receptacle placed on top.

"To start, simply screw plug into the socket and turn on. The stove may be removed by pulling the end of the plug out.

"This stove is perfectly safe and fireproof, as all the electrical parts are insulated and the heat resisting element protects the table top. Like any other hot surface, the top must be kept away from inflammable surfaces, and must not be packed away until cold.

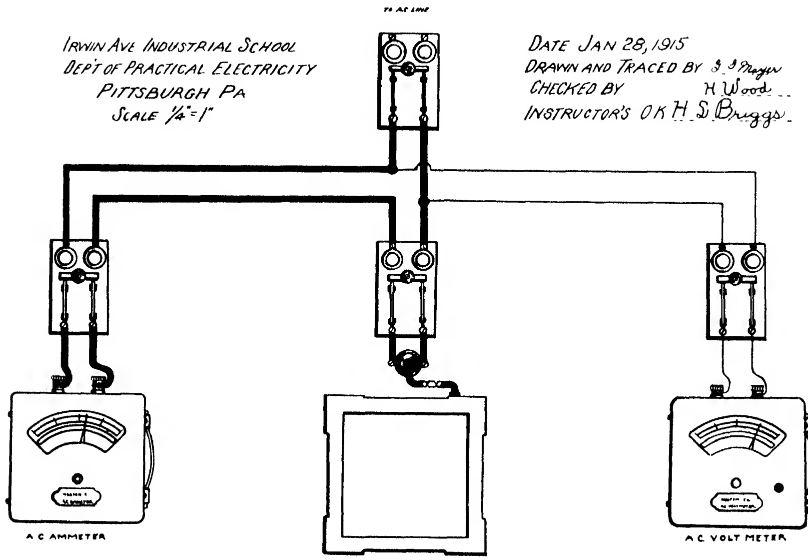
(Signed) "HAROLD WOOD."

## EXPERIMENT No. 6

## TESTING "The Toastove"

"As we had not reached the instrument work in our unit course, all tests on the 'Toastove' had been made by putting it to work on the job.

"Mr. Ball always sends Mr. Briggs any printed matter of interest that comes into his office or that he thinks would be of use to us in our work. In this way we got hold of Monograph 'B-4' of the Weston Company.




Slide No. 538
Testing "THE TOASTOVE" with Weston Instruments

"When we found what other schools had been doing in testing commercial toasters, we decided that it was about time that we tried the same thing with ours. We looked over our job cards and persuaded our instructor that we were ready for instrument work anyway.

"We selected the first toaster we ever built for the test. We called it 'Old Ironsides' because this one was made of iron instead of copper, and it has been banging around the shops, from heating the glue pot, weighing sixteen pounds, in the print shop, to being used as a foot warmer the day the room was so cold, and it is still in commission.

"We had to study up in the Monograph on the operation and construction of the instruments before we were allowed to use them. We found that all instruments were more or less delicate, expensive and quite easily burned out. We decided to follow the 'Safety First' idea, and tried to work out a 'foolproof' switchboard, as we were taking no chances on shorts.

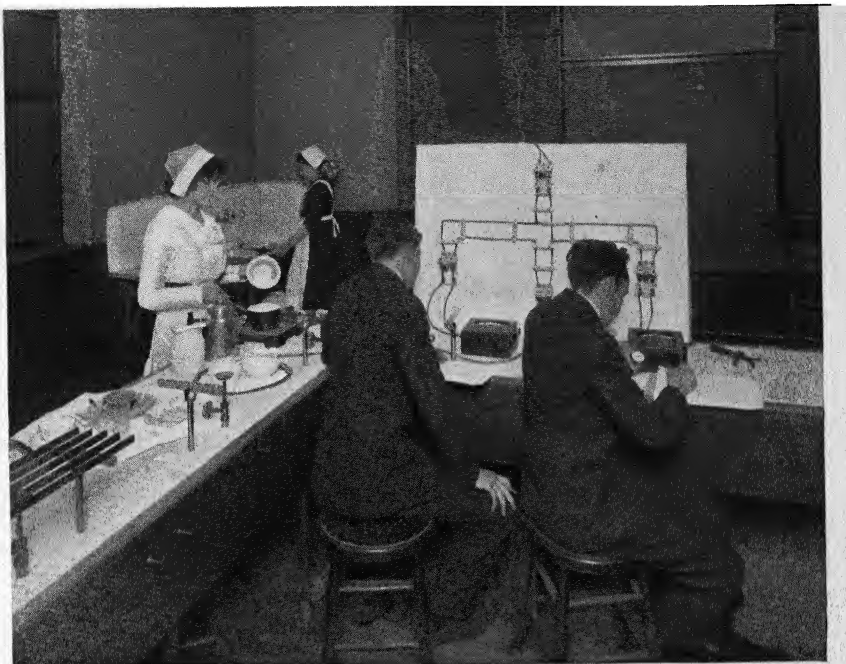
"We had a main double pole single throw switch fused for six amperes, with a switch and five-ampere fuse for each leg. We made the board light so as to be portable and so wired that our circuit would be plain enough for even the 'B' group to understand.

"The ammeter goes on the left; receptacle in center is for attachment plug of article to be tested; and voltmeter is on the right. The switches enabled us to throw in any part of the circuit at a moment's notice, as you must move quickly when making a test, and time is money with electricity.

"We turned our sketch over to Mayer for drawing and tracing, as it fitted in well with his third unit drafting. Wood checked the drawing, and Mr. Briggs O. K.'d it. We then wired according to it.

"When we had a full outline of what we wanted to do and it was O. K.'d, we shifted to the Domestic Science Department, as Miss Mates had offered to help us out on the cooking end of the job.

## COOKING BREAKFAST ON THE "TOASTOVE"



Slide No. 539

Dept. of Domestic Science, Irwin Ave. Industrial School, Pittsburgh, Pa.

"We first wanted to find the cost of cooking an actual breakfast, and so Miss Mates had Anne Barr plan a breakfast for us. It consisted of grapefruit, coffee, soft boiled eggs and toast.

"When it comes to getting things down fine in a cost test, the size and shape of pots and pans count, and we discovered that our coffee and egg pans were high, with small bottoms, making them hard to heat on a toaster top. This lowered the efficiency as we found that the toaster operated on less current when entirely covered, due to increased internal heat; therefore higher resistance of the heating element.

"We kicked about the shape of the pans, but there were thirty girls and only two of us, and so we lost out. Then, in the midst of the test the girls had to cool something and opened a window less than six feet away from the toaster, leaving the pots in a strong draft of cold wind, which, of course, caused a loss of heat. We kept still this time, however. An electric iron was also running, off and on. This probably accounts for part of the variations in readings.

"The water for the coffee test had been standing a short time, but in the case of the eggs it was drawn directly from the faucet, reading at 50° F., as it had been running.

"I took the ammeter readings and temperature while Wood checked the voltmeter and called the time. We tabulated our readings and plotted a curve of results.

"'Old Ironsides' was rated at 400 watts and tested out at averages of 376 on the cost test and 380 in the efficiency test. The voltage was below 110 in both cases.

"Following is our table of results in cost test:

| Time | Amps. | Volts | Material Being Prepared | Temperature | Amount |
|---|---|---|---|---|---|
| 2 | 3.75 | 104 | Coffee . . . . . | 60° F. | 2 Cups |
| 4 | 3.75 | 104 | Coffee . . . . . | | |
| 6 | 3.75 | 103 5 | Coffee . . . . . | | |
| 8 | 3 65 | 102.5 | Coffee . . . . . | | |
| 10 | 3.65 | 102 | Coffee . . . . . | 212° F. | |
| 2 | 3.65 | 103 | Soft Boiled Eggs . | 50° F. | 2 |
| 4 | 3 65 | 102.5 | Soft Boiled Eggs . | | |
| 6 | 3.65 | 102 | Soft Boiled Eggs . | | |
| 8 | 3 65 | 102 | Soft Boiled Eggs . | | |
| 10 | 3.65 | 102 | Soft Boiled Eggs | 212° F. | |
| 1 | 3.75 | 109 | Toast . . . . . | | 4 Pieces |
| 2 | 3.65 | 108 | Toast . . . . . | Brown and crisp, | |
| 3 | 3 65 | 108 | Toast . . . . . | both sides | |

### COST OF CURRENT FOR PREPARING BREAKFAST

| | | |
|---|---|---|
| Watts (average) | | 376 |
| Watt-hours | $\frac{23}{60} \times 376 =$ | 144 |
| Kw.-hours | 144 ÷ 1000 = | .144 |
| Cost per kw.-hour | | $ 10 |
| Cost of breakfast | | .0144 |

"As the toaster was not operating under the best of conditions in the first test, we made a second, using a kettle to determine actual operating efficiency, that is, relation between input and output, with the following results:

### EFFICIENCY TEST
(Kettle Hot)

| | |
|---|---|
| Weight of water | 2 lbs |
| Temp. rise | 20° F. |
| B. T. U. | 40 |
| Watts | 380 |
| Time | 2 Min. |
| Watt-sec | 45600 |
| Equiv. | 43.23 B T.U. |
| Efficiency | 92.4% |

"Experiment completed January 22, 1915.

"Report written by:
(Signed) "R. ALEXANDER.

"Report checked by:
(Signed) "H. WOOD."

# ELECTROTYPING

In "Electro-Deposition," by Alexander Watt, published in London in the year 1885, the following will be found which relates to a generator invented by Edward Weston, which has long since been withdrawn from the market:

### THE WESTON DYNAMO-ELECTRIC MACHINE

"The introduction of this clever machine from the United States, in 1874, by Mr. A. Van Winkle, of the firm of Condit, Hanson, & Van Winkle, gave an extra-ordinary impetus to the nickel-plating industry throughout the whole country. Being of small dimensions, of compact form, and yield-

ing an abundant current, it became readily adopted by the Plating Company, Limited, of Kirby Street, London, in that year, and though he had some difficulty in overcoming the prejudices of the foreman of that establishment, by insisting upon a fair trial being given and taking care that no obstacle should be thrown in the way, he succeeded in securing not only a fair trial of its capabilities, but its ready adoption by the company. The Weston machine was subsequently adopted by a great number of firms, amongst which were many that would probably never have embarked in nickel-plating but for the facility which this machine offered in generating the requisite electric current at the cost of less than one horsepower. There can be no doubt whatever that the remarkable development of nickel-plating in this country and in America, as also the substitution of electrotyping for the stereotype process in American printing establishments, are greatly, if not chiefly, due to the introduction of the Weston dynamo-electric machine."

Electrotyping is not only a highly useful art, but offers a fascinating means for teaching electro-deposition. Many high school text books refer to electrotyping * and give directions for making electrotypes by methods adapted from professional work.

It is unfortunate that the educational value of commercial methods is often diminished because expensive and complicated devices are employed to reduce labor and improve the product. These adjuncts are difficult to introduce when working on a small scale, but if omitted, the practical method of which they form a part is no longer practical, and the results are poor.

We arrived at the above conclusion after visiting a large manufacturing company which makes a specialty of line cuts, electrotypes and half tone work, and decided that the fundamentals of the art should be taught by a simple and inexpensive method, which would be interesting to the student and yet make good results possible.

In order to obtain such a method, we enlisted the services of three high school students, supplied them with a limited stock of raw material and apparatus, induced them to experiment at school and at home, prepare their own solutions, develop a method and write a report.

We publish the latter, which seems to have educational value, since the operations are clearly described in proper sequence and permit tests or inspection at each stage, and the quality of the final product depends entirely upon the care with which several simple tasks are performed. Hence an exercise based upon it is likely to be popular and a stimulus to wholesome competition.

Our original plan was to use the finished work, as well as the equipment of these students for illustrations, but with practice their specimens became so exceptionally good that we decided it would be unfair to call them average productions. Therefore, in order that they might serve as object lessons, we sent an assortment of them, good, bad and indifferent, to several instructors who had consented to co-operate with us in the matter, and requested them to furnish others prepared independent of our auspices, but more or less in accordance with the method.

In reference to the report, we made a tentative suggestion that our blue pencil could be applied to good advantage in the elimination of certain idioms, desultory statements, etc., but the boys stoutly objected, stating that it was "rough enough on them to can most of their finest specimens, without docking their report." They claimed in substance, that since they had experimented without assistance for over a year (off and on), they should at least be permitted to issue a report in their own style, especially since it was not a literary exercise, nor even intended for instructors, but was direct information from them to other students, who would probably appreciate their diction, even if teachers did not.

Their arguments seeming valid, a special dispensation was granted, and the report is printed verbatim, with apologies to all purists.

* See "Household Physics," Butler, p. 229; "Elements of Electricity," Timbie, p. 334; "Elements of Physics," Hoadley, p. 326; "Lessons in Practical Electricity," Swoope, p. 82; "A High School Course in Physics," Gorton, p. 398; "Laboratory Exercises in Physics," Fuller & Brownlee, p. 250; and others.

EXPERIMENT No. 7

# AN ELECTROTYPING METHOD

DEVELOPED UNDER THE DIRECTION OF

MR. W. J. DUMM

INSTRUCTOR IN CHEMISTRY, BARRINGER HIGH SCHOOL, NEWARK, N. J.

APPROVED BY

MR. CHARLES E. DULL

INSTRUCTOR IN PHYSICS, SOUTH SIDE HIGH SCHOOL, NEWARK, N. J.

Slide 540
Developing an Electrotyping Method

"After much experimenting the following method of making electrotypes was developed by our cousin, Rogers B. Johnson (Harvard '17), while taking a post-graduate course at the Barringer High School. Suggestions were obtained by him from Mr. W. J. Dumm, Instructor in Chemistry, and from various practical works on the subject.

### OUTFIT REQUIRED

"Plating tank, anode, cathode, primary cell, hydrometer, rheostat, Weston milli-ammeter, copper-sulphate, sheet copper, copper wire, paraffin, beeswax, graphite, small brush, dies, small tin dishes, solder, soldering acid, soldering iron, Bunsen flame, potash or salsoda, silver polish, powdered pumice and **Patience.**

## PLATING TANK

"Any glass or porcelain jar will do for a plating tank. For small work we found a peanut-butter jar quite satisfactory. Later we secured a large oblong storage battery jar, 6 × 8 × 18 inches, and with much difficulty persuaded a glass man to cut it down to 6 × 8 × 6 inches. He said it was impossible, and that it would crack, but he finally tried. It did split a little down the corners, but a dip in hot paraffin fixed that.

## ANODES

"We used two pieces of common sheet copper, each 6 × 8 × 1/16 inches, covering both sides of the tank. Electrolytic copper is best.

## COPPER-SULPHATE SOLUTION

"Prepare a saturated solution of copper-sulphate. Test it with a Beaume acid hydrometer and if it does not register 20 at room temperature, add water or sulphuric acid until it does. A solution which registers much off 20 will give a lumpy and brittle deposit. A little starch added to the solution will improve the deposit. A newly prepared solution seldom works well, so do not get discouraged if your first results are poor. Try again after a few days.

## MOULD

"The cathode is made by pressing the object to be reproduced into wax covered with graphite. This seems simple and easy enough, but so does the work of a lightning sketch artist. The wax should be a mixture of 60% paraffin and 40% beeswax. Paraffin settles in the center when cooling, pure beeswax is said to bulge, and the combination is supposed to produce a balance. We were not able to get any beeswax which was pure, according to this test, but found that a mixture as above works better than paraffin or beeswax alone.

"The mixture, which we will call 'wax,' is melted, and enough is ladled into a small dish to fill it. The dish should be about one-half inch high. The wax is allowed to cool until a tough coating is formed on the surface. Very finely powdered graphite is then dusted on the surface with a 'camel's hair' brush, and rubbed in with the ball of a finger. (Powdered pencil lead will not do; it is too coarse. Flake graphite is also N. G.) The loose grains are then blown off, and the matrix is ready for the next operation.

## THE ORIGINAL OR DIE

"The article to be reproduced may be anything which has enough relief to show up well (Figs. 1 and 7, Slide No. 544), but small tokens, medals, intaglios, stick pins, cameos, seals, etc., are easiest to handle.

"If the die has no handle, one may be made by sticking on a piece of sealing wax.

"After finishing with the die, any sealing wax which sticks to it can be dissolved off with alcohol.

## THE MATRIX OR CATHODE

"The die is carefully cleaned and dusted with graphite and then pressed steadily into the wax, either by hand or by means of a clamp or vise. A good way is to use a small piece of board to squeeze it. We used an old letter press part of the time. The wax must not be too hard, because if it is, some of it may stick to the die; and it must not be too soft, because it will then give a poor imprint and may even squash. A little practice with a toothpick * or pin will determine this point; but don't stick holes into the surface you intend to use.

* Why not with a thermometer?—COMPILER.

"While the die is in the wax, make cuts with a knife blade around it down to the bottom of the dish, leaving about a half-inch margin.

"To remove a die having no handle, turn the dish bottom up and press or tap on it.

"Lay the matrix aside until the wax is quite cold and hard. (If you are in a hurry, put the dish on ice.)

"When hard, the wax may easily be chipped out of the dish. It is then provided with a hanger made of copper wire with a loop on one end. The diameter of the latter should be about one-half inch larger than the imprint.

"The loop is melted into the wax by means of a piece of warm (not hot) metal.

"When cool the wax is scraped with a knife blade until a little of the surface of the ring is exposed and bright. More graphite is then laid on with a brush, from the edges of the imprint to the ring. (Fig. 2, Slide No. 544.)

"Any graphite outside of the ring should be scraped off, since if left, it wastes deposit just that much.

"A lead **(not iron)*** weight may be stuck to the bottom side of the matrix by slightly warming it. This will act as a sinker and prevent the matrix from heading for an anode, which it surely will if it floats and is attached to a fine wire.

## CURRENT

"Current may be obtained from any d. c. source. We first used dry cells, and when they were exhausted, we made Nodon valves and electrolytic rectifiers. But our aluminum was impure, so that we got precious little d. c., and ran up such a big bill for a. c. service that we had to quit; and tried a carbon iron cell. This was made by using a marmalade jar. Liquid was: water 60 parts, sulphuric acid 20 parts, and nitric acid 20 parts. Active element was a piece of gas pipe. Inactive element was a carbon from a dry cell. Current was strong. So was the smell. The fumes were something fierce, and the iron became hot. Next we tried gravity cells with type metal for anodes, but got poor results because type metal has too much lead in it.

"The problem of getting along without zinc (which we were short of), was finally solved by using gravity cells in multiple, with iron gas pipe for anodes. They gave good results and very steady current.

## RHEOSTAT

"A rheostat for current regulation is necessary. For very small work an ordinary plug resistance box, such as is used in most high schools, may be connected in the line. But if the current is over ¼ ampere, a ventilated rheostat should be used. We made one having 40 steps of about 1/10 ohm each, which can stand a current of several amperes, but it was not intended for this work. The quickest and easiest way to make a rheostat for plating is to stretch a resistance wire between two nails and twist a piece of copper wire around it to make a sliding contact. German silver No. 30 wire has a resistance of about 2 ohms per foot, and will carry over an ampere without getting too hot to touch. Its diameter is 0.010 inch. Three feet will be enough, and 1 ampere will plate 100 square centimeters, or about 16 square inches, which is more than enough to handle at one time.

"Of course, if a direct current service line is to be had, a lamp-bank rheostat must also be put in series. But plating with a current at 110 volts is a nuisance, because you are likely to have shorts and blown fuses and a shock now and then which may make you drop and spoil things. Take it from us, unless you are so lucky as to have a storage cell, a primary cell is best; and if you haven't got one, then make one.

---

* Professional platers say that iron spoils an acid copper solution.—COMPILER

## CURRENT DENSITY

"The area of plating surface should be carefully determined and noted. The current density should not exceed 0.01 ampere per square centimeter for an acid copper solution.*

"A Weston direct current milli-ammeter, range 1 ampere, having a scale with 50 divisions is best for small work.

## PLATING

"If you use only one anode the matrix should face it, and be at least 2 inches from it—three is better. If the cathode is too near the anode, the plating will skimp the low spots. A copper rod or bare copper wire is convenient for supporting the matrix or cathode if you have a large tank and double anodes. In that case the position of the cathode is of no consequence, provided it is not too near an anode.

"Of course, the + pole of the cell is connected with the anodes and the circuit is completed through the cathode, the ammeter and the rheostat. Plating begins at the ring and works in. This is because the graphite surface has an enormous resistance compared with copper; but just as soon as a 'flash' coat covers the cathode, current increases. So watch your ammeter. It takes from twelve to forty-eight hours to plate a stiff coat, which should be from 0.005 to 0.015 inches thick. When the surface is evenly coated the current may be boosted somewhat, but it is a mistake to boost it when any graphite remains uncoated, because that part may then be coarse in appearance and lack detail. As a rule, boosting the amperage to get quick results is of no more use than doubling the temperature of an incubator in order to cut the hatching time in half, and if you boost it too much, you will get **mud**; and it's no help to take the matrix out of the solution every few minutes in order to see how it is getting along.

"If spots remain unplated, it is an indication that they have not been sufficiently covered with graphite. Then the best plan is to wash the matrix in cold water, and when dry add graphite with the brush and resume plating The more thoroughly the graphite has been worked into the surface in the first instance, the better the results will be. But patching as a last resource is not bad.

## STIFFENING THE DEPOSIT

"When the plating is complete remove the matrix, using the wire as a handle. Wash it in cold or warm water. Then place in a dish and melt off all the wax that will run. Do not try to wipe or clean the electrotype, unless you have a heavy deposit, or you may damage it. Place it on an asbestos mat or else on a tray containing some fine powder which is not affected by the heat. Powdered pumice is good. Spread a little soldering flux on the surface with a soft rag tied to a stick. Have the soldering iron quite hot, but not red hot. Melt enough solder to cover the surface by holding the solder against the iron. Let it drip. Then hold the iron on the solder and it will flow and spread. Do not rub the deposit with the iron or poke it with the point. In fact, do not touch the copper at all. If this operation is performed while the deposit is still clean and untarnished the solder will take hold. The wax on the surface will do no harm. The best soldering flux for the purpose is made by dissolving all the zinc it will eat in a 50% solution of muriatic acid and water. (See all replicas on Slide No. 541.)

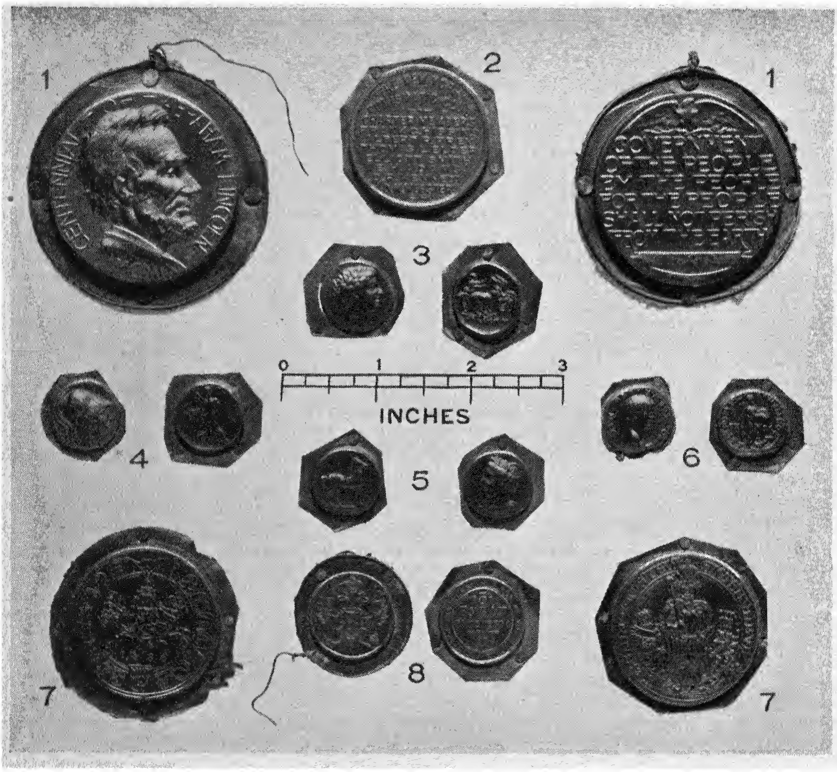
## TRIMMING AND POLISHING

"Trim off the edges with a pair of shears. File the back smooth, and if you wish, plate on a little copper; but if you do this cover the electrotype surface with wax. Clean by boiling in potash or salsoda solution. Brighten with a rag and pumice, and finish with rouge or silver polish.

* The Hanson & Van Winkle Co., Newark, N. J., manufacturers of low-voltage dynamos, plating solutions, etc., state in their Bulletin No. 105, that the current density for an acid copper solution should be from 10 to 12 amperes per square foot. This would be in the proportion of 0.0107 to 0.0129 ampere per square millimeter. So the boys' figures, obtained by experience, are quite close to commercial practice.—COMPILER.

## STAINING

"The heating effect of the solder causes the graphite to combine with the copper, forming a tint resembling bronze. This can be removed by a quick dip in diluted nitric acid, or by scrubbing. A stain resembling bronze can also be obtained by dissolving a very small quantity (1 oz. to the gallon) of liver of sulphur in water.* When perfectly clean copper is dipped into it; it turns brown and finally blue-black. Any intermediate shade may be obtained. Lacquer may be used to protect the surface; and you will finally have as a reward for your labors, a real replica which will be an exact reproduction of the original, or a fairly good electrotype, more or less like the die; or if you were not blessed with skill or luck, you may have a botch.




Slide No. 541

Replicas of Coins and Medals made by Austin and Conrad Frey

(1) Abraham Lincoln Centennial Medal.
(2) Club Medal.
(3) Gold Coin, Stater of Philip II, of Macedonia, 359 to 336 B. C.
(4) Gold Coin, Stater of Alexander the Great, 336 to 323 B. C.
(5) Gold Coin, Stater of Carthage in Africa. Issued for about 100 years from B. C. 340.
(6) Gold Coin, Roman Emperor Nero. A. D. 54 to 68.
(7) Silver Thaler of Tyrol, dated 1486, frequently known as the Guldengroschen.
(8) Platinum Coin of 3 Roubles, issued in 1834 by the Czar Alexander I, of Russia.

The rare ancient coins and the perfect modern medallions required to obtain these replicas were kindly loaned by Mr. Albert R. Frey, of the New York Numismatic Club.

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* Solution as given is too strong for delicate coloring. Use about 10 grains (0.65 gram) to a pint of water.—COMPILER.

WARNING!

**"DO NOT ATTEMPT TO REPRODUCE U. S. COINS OR EVEN MAKE IMPRINTS WITH THEM. IT IS AGAINST THE LAW.**

## CARBON FLOUR AND BRONZE POWDER

"We have also tried carbon flour instead of graphite, but have not done enough work with it to be able to decide whether it is better. It is much dirtier and, therefore, should have some advantages.

"We examined carbon flour and graphite under a microscope and noted that the carbon flour is finer in grain than the graphite. There are bright specks in it which seem to be aluminum. There seems to be no difference in the current required; and we have obtained several perfect replicas with the carbon, so it's up to you.

"Other preparations upon which copper may be deposited are the so-called gold and bronze enamels. These are powders which look enough like the genuine article to be often sold as such, but are (we think), oxides of copper. They may be used dry, in the same manner as graphite.

"We do not deserve any credit for finding this out. Some electrotypes made from half-tones were shown to us, and our attention was called to the fact that bronze powder had been used instead of graphite. So we tried it. No. 1 (on Slide No. 541) was made that way.

## FREAK PLATING

"Almost any substance can be given a coat of copper providing it is dry, as follows: Place it in hot wax and let it remain until all the bubbling ceases. Remove and allow to cool. Then coat thoroughly with graphite. Connect a wire and plate. Afterwards finish or leave it in the rough as preferred. In this manner we plated leaves, twigs, walnuts, peanuts, stalactites, dead bugs and grasshoppers, horse flies, etc. The surface is rough, however, because the proper way to plate is just the reverse of electrotyping, since the exposed instead of the hidden side is the one to be eventually finished, and, therefore, the deposit must be polished several times to prevent it from forming a rough or crystalline surface. This cannot be done with small and delicate objects.

"We also found out that we do not have to boil things in wax and get them dry before they will plate.

"We took green leaves and twigs, also vegetables, and plated them as follows:

" 'Take equal parts of carbon flour and graphite, mix them together and add a little glycerine and water, and work up a stiff paste like shoe blacking. Then rub this on the article to be plated with an old tooth brush, daubing it all over. When it has dried a little go over it again with a dry brush to smooth down. Then plate.'

"There are several kinds of stove polishing pastes on the market which you can buy for a nickel, and which are just as good as the stuff we made up.

"Some leaves and stalks are naturally sticky—fur and spruce, for instance. These can be prepared for plating by rubbing with dry carbon flour, graphite or bronze powder.

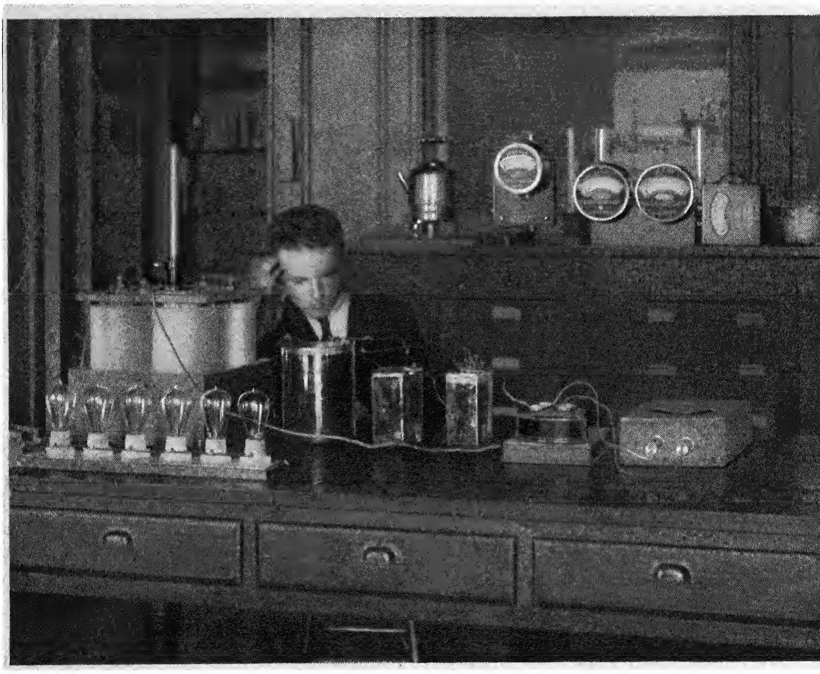
"AUSTIN R. FREY,
"CONRAD P. FREY.
"South Side High School,
"Newark, New Jersey."

# A REPORT ON ELECTROTYPING*

BY

MR. H. C. PHILIPPI

STATE NORMAL SCHOOL, BELLINGHAM, WASHINGTON



Slide No. 542
Electrotyping with a rectified current obtained from an a.c. service line

**(Excerpts from Correspondence and Reports.)**

"Oct. 27th, 1914.

"I am in receipt of your letter of Oct. 20th, relative to electrotyping work for Monograph 'B-5.' My class and I will be more than glad to co-operate with you. The idea of co-operating with a great manufacturing company is a powerful stimulus to students, and we shall take advantage of every such opportunity that is presented."

"Nov. 26th, 1914.

"I received the box of electrotype material in good condition, and the members of my class are already studying the boys' report. We are anticipating much pleasure as well as profit from the work."

"Jan. 30th, 1915.

"I am sending you to-day, by Parcel Post, three of our first electrotypes. We expect to have better ones in a short time. Some of the members of the class are now making replicas of medals, souvenirs, etc., entirely

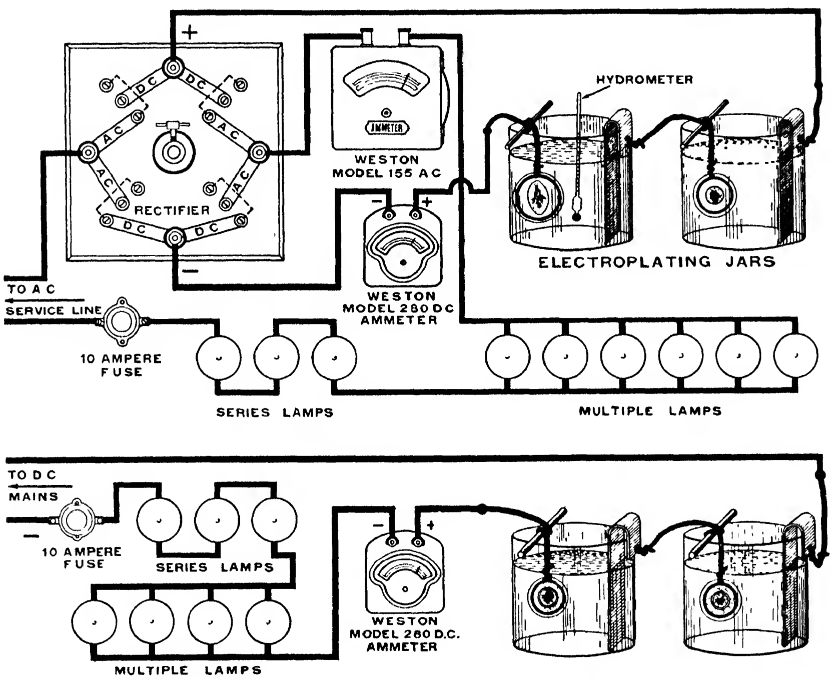
* This is an independent attempt on the part of a student to give instructions relating his modification of Johnson's method.—INSTRUCTOR'S NOTE.

without assistance from me. As soon as they have acquired sufficient experience, I shall have them electrotype various forms (receipts, program blanks, etc.), which are set up in our school print shop, and are used in our school administration. If the results are satisfactory, these electrotypes will be used in the school printing.

"Whether you can use any of our material or not, we are getting, and expect to continue to get, a great deal of pleasure and profit from this line of work, and we hope we may have the privilege of keeping in touch with you in the future."

EXPERIMENT No. 8

# ELECTROTYPING WITH COPPER




Slide No. 543
Electrotyping at the State Normal School
Bellingham, Washington
(Reproduced from Student's Sketch)

EQUIPMENT:

(1) A coffee can cover.
(2) Beeswax and paraffine.
(3) Graphite and camel's hair brush.
(4) An object to take the impression from.
(5) An earthen or glass jar with electrolyte.

(6) An a.c. with lamp rheostat and rectifier, or d.c. with lamp rheostat, or wet cells.

(7) Solder, soldering flux and type metal.

(8) A metal polish and varnish.

(9) Weston ammeter.

I. A common coffee can cover will do to melt wax in. This should be large enough to leave a border of a half an inch around the intended impression.

II. Melt together beeswax and paraffine in the can cover till its level is nearly level with the rim of the cover. A half and half mixture seems to give the best results.

III. When the wax is nearly cold, brush powdered graphite on the surface of the wax and face of the model with a camel's hair brush. The reason a camel's hair brush is suggested is because it is fine and does not scratch the surface of the wax.

IV. Before the wax gets cold, force the model well into the wax either by pressure of the hand or in a vise. Allow the wax to get cold, then remove the object and graphite the impression thoroughly. About half an inch from the impression scratch a line around the impression and graphite well. Put a small wire in this cut and graphite. The two ends of the wire can be twisted, leaving about an inch or two to suspend it in the electrolyte. Graphite is a good electrical conductor, consequently it is used.

V. The jar (glass or eathenware) in which the wax impression and sheet copper are suspended contains a solution of copper sulphate with a small amount of sulphuric acid. The specific gravity of wax is less than water, consequently the impression will have to be weighted. Suspend the impression with the graphited surface towards the sheet of copper.

VI. If an (a. c.) alternating current is used, a rectifier will be required in addition to the lamp rheostat. It consists of some lead and aluminum plates in an electrolyte.* When the a. c. is run in through a certain way, it produces a d. c. at the other terminals. This rectifier is required as electroplating can be done only with a d. c. The lamp rheostat must be connected in series in the a. c. with the rectifier as can be seen in the diagram. One to three 16-candlepower carbon filament lamps burning in series with rectifier give very good results.

For a battery plating outfit the positive electrode of the battery will be connected to the copper plate in the jars. An Edison cell works well as it does not polarize. Connect an ammeter in series. Connect the wire from the impression to the negative electrode of the cell.

If it so happens that the copper has not plated the whole surface perfectly, rinse the impression off and graphite the bare spots. The impression should be put back in the electrolyte and subjected to another plating. When the replica is plated thick enough so it will not warp easily, it can be taken from the jar and a flame applied to it to melt the wax.

VII. To make a rigid replica, it is better to "back" it with type metal. This is done by applying a soldering flux and melting solder over the whole surface. The type metal can be melted into it now. The solder must be melted in it first because type metal will not adhere to copper readily. With a file and tin snips, the edges can be trimmed and a smooth job being the result.

VIII. If a bright coppery color is desired it can be obtained in the following way: First polish the surface with a metal polish and then wipe it with a rag soaked in varnish.*[2] This prevents the copper from corroding and discoloring.

Submitted by EASTMAN W. HOWELL,
Eleventh Grade, High School Department, Training School.

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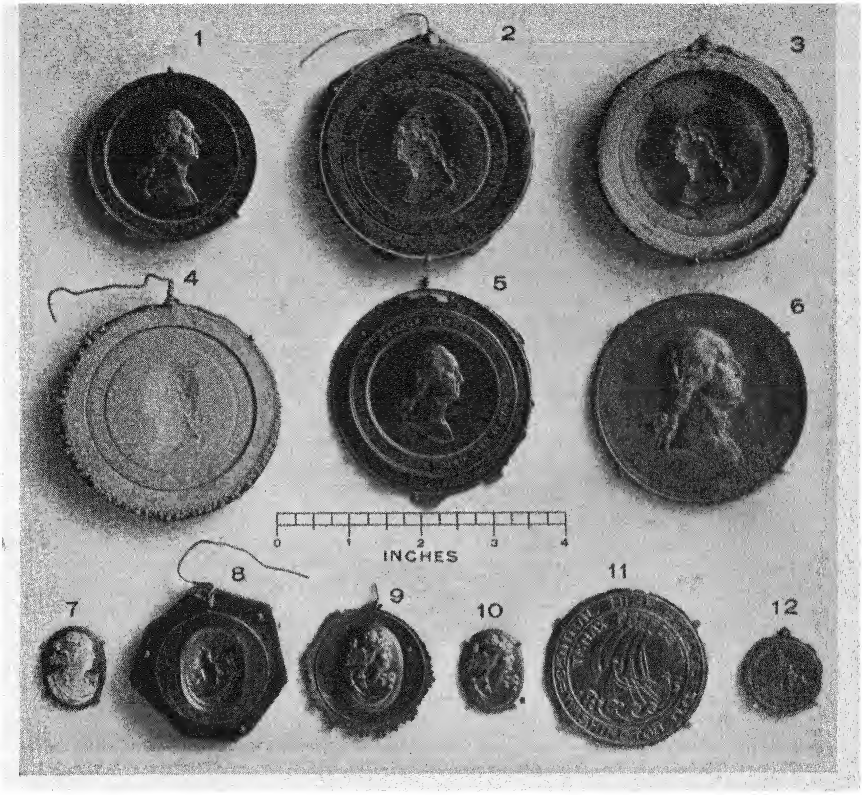
* Usually a solution of sodium-bicarbonate or ammonium-phosphate.—INSTRUCTOR'S NOTE.

*[2] Better to apply a thin coat with a brush.—INSTRUCTOR'S NOTE.




Slide No. 544

Specimens of Electrotyping Work from the State Normal School, Bellingham, Washington, and the Central High School, Washington, D. C.

(1) Original Medallion.
(2) Graphited imprint in wax with conducting wire.
(3) A partial deposit interrupted to show formation.
(4) Complete deposit on wax.
(5) Obverse of electrotype stiffened with solder.
(6) Replica.
(7) Cameo.
(8) Graphited imprint
(9) Complete deposit.
(10) (11) (12) Replicas.

## EXPERIMENT No. 9

# AN EXERCISE IN ELECTROTYPING

### PERFORMED UNDER THE DIRECTION OF

## MISS LILLIAN PACE

### INSTRUCTOR IN PHYSICS, CENTRAL HIGH SCHOOL, WASHINGTON, D. C.

"The work performed in this report was based on the article on electrotyping, written by Austin and Conrad Frey.

"My plating tank was a thick oblong glass jar, 9 × 6 × 8 inches. The solution, according to directions, should have been a saturated solution of copper sulphate, to which sulphuric acid was added until the density was 20. I apparently saturated my solution, but my hydrometer, which I considered accurate, registered only 8. I raised the density to 14 by adding sulphuric acid, but, as I did not like to put in any more acid, I used it as it was.

"The anodes were made of two very long pieces of heavy bare copper wire bent so as to form two bundles. This was necessary, as I had no copper sheeting.

"The source of current was an Edison storage battery of two cells, e.m.f., 3 volts. I used a current density of .01 ampere per square centimeter. The ammeter was a 1.5 ampere Weston Model 45 instrument, No. 9054.

"The rheostat was a 98-inch piece of No. 18 German silver wire stretched along the window frame. The rheostat clip was made by fastening a copper strip, to which was fixed a wire, in the jaws of an ordinary wooden clip. The resistance was about 5 ohms.

"My switchboard was a board upon which were fixed three sockets with fuses. There were used to put in or take out of the circuit the ammeter, which was always taken out at night, and the rheostat. The fuses were not intended to protect the instrument as their capacity was too great.

"When putting the graphite on the wax, I used a piece of waste instead of a brush.

"After putting the matrix in the bath, the current increased slightly as the graphite became coated, so some regulation was necessary at first. After the graphite was covered, however, the current remained constant. I found that twenty-four hours' immersion would make a thin but fairly stiff coat, but that from five to seven days were necessary to get the thickness of an ordinary medal. After the plating, solder was put on the back, the electrotype sawed out, the solder filed down and the face cleaned and stained to a bronze color.

"The electrotype that gave me the most trouble was the large Central High School seal. (Slide No. 544, Fig. 11.) The original was a paper embossing stamp, of which the jaws were not more than one-quarter of an inch apart. As a cake of wax could not be successfully inserted and withdrawn, I was about to give up when a fellow student suggested putting graphite on a piece of paper. I made his idea practical by putting a coat of wax on a piece of paper and taking the impression on that. The reproduction of the seal of the City of Washington has not the fineness that it should, since the die itself had at one time been heavily plated. Indeed, I might say my greatest difficulty lay in securing suitable dies.

(Signed "STANLEY MALCOLM CAMERON,
"Senior Class. Age 17.

"January, 1915."

## THE ARC LAMP

In 1881 an "International Exhibition of Electricity" was held at Paris and a report relating to the exhibits, etc., was prepared by Major David Porter Heap, and issued by the United States Government printing office at Washington in 1884.

It is significant as an indication of the state of the art of electrical measurement, that although military telegraphs are illustrated and described, also torpedo apparatus for firing by observation, and telephones as well as galvanometers were used in the manipulation and testing of circuits, not one instrument for the practical determination of voltage was exhibited, and the only apparatus for the commercial measurement of current depended upon the deposition of copper, so that the current consumed had to be determined by weighing a cathode!

It was to be expected, therefore, that the only test for incandescent lamps was to run them until they burned out, and for generators to overload them until they smoked.

Several arc lamps were exhibited, among others the "Weston Regulator." Their mechanical construction is described in detail and in every instance a conscientious attempt made to do justice to any features of merit, but the pitiful lack of facilities for quantitative measurements is forcibly brought home by the fact that all the information in relation to the efficiency of the Weston arc lamp is contained in one short paragraph as follows: "The mechanism is exceedingly simple, the apparatus is very sensitive, and the light produced is very steady."

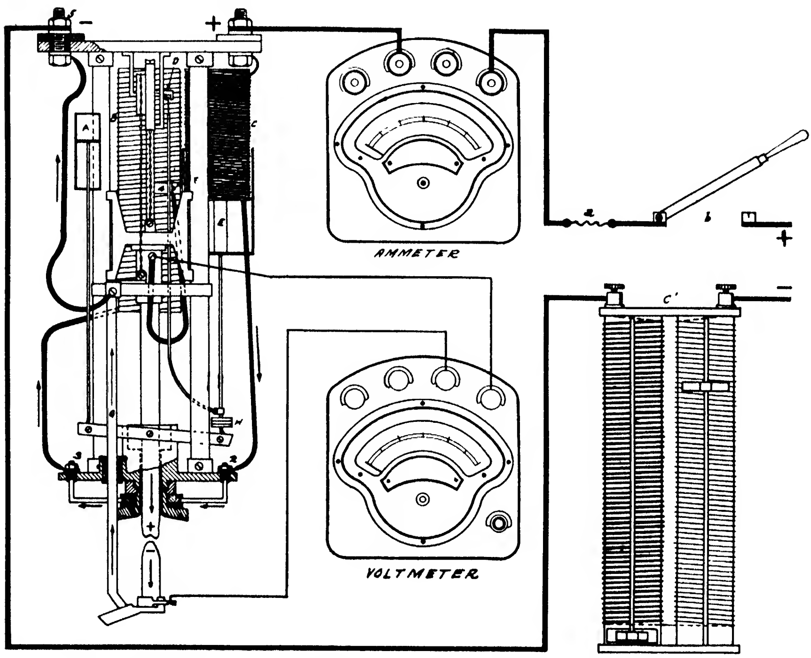
As an illustration of the advance that has been made, not only in the art of measurement, but also in the scope of practical school work, it gives us pleasure to offer the following verbatim report.

# THE ARC LAMP

## A NEW TYPE OF EXPERIMENT FOR HIGH SCHOOLS BY

EARL R. GLENN

INSTRUCTOR IN PHYSICS, THE FROEBEL SCHOOL, GARY, INDIANA




POWER MEASUREMENTS ACROSS D.C. ARC

KEY:- a - FUSE; b - SWITCH; C' - RHEOSTAT

Physics Dep't. Froebel School Gary, Ind.
Drawn and Traced by Mack Kowalewski
Checked by E. R. Glenn. Dec 1, 1914.

Slide No. 545
Testing an Arc Lamp with Weston Instruments

I

Significant and interesting experiments are always in demand. The material here described has proved very satisfactory, and it is submitted with the hope that other instructors of physics may extend and improve the exercise. Recently we came into possession of ten second-hand flame arc lamps, at a cost of about $10 each. The following experiment was devised to use in regular high school work and in applied electricity courses for adults. While the power measurements are being made by one group, others can determine resistances, make drawings, study questions, etc., etc. Or all of the work can be given as a lecture-table experiment, members of the class taking the data and completing the computations.

II.

Experiment: The Flame Arc Lamp for Multiple Circuits.

## APPARATUS

Flame arc lamp, ammeter (Weston Model 280, triple range, portable ammeter), voltmeter (Weston Model 280 triple range, portable voltmeter), Wheatstone bridge (slide wire or other type), resistance box, galvanometer (Weston student galvanometer, Model 324 or 375), insulated wire, screwdriver, mica, adjustable wrench, rheostat (4 or 5 ohms), wire pliers.

## METHOD

Part A. (1) First hang the lamp from a support so that it swings freely in a vertical position. Remove the case and inspect the different parts carefully. Make a rough sketch of the regulating coil, resistance and arc. Submit to the instructor for approval.

(2) Examine all binding posts and connections to be sure that the lamp is in working order. Lift the core of the electromagnet to test the action of the friction clutch in "striking" the arc. If the lamp is out of order list the trouble as shown in Part A-2, under Data and Results, and ask the instructor for directions.

Part B. (1) Refer to Weston Monograph B-2, pages 23-26, or to second edition, B-1, B-2 and B-3 combined, pages 55 to 59 and study the Wheatstone bridge method of measuring an unknown resistance. Ask the instructor to derive the formula X equals $\frac{AR}{B}$. What precautions must be observed in using this bridge?

Connect the rheostat as X in the Wheatstone bridge and measure its resistance. Use lengths of wire for A and B, as shown in Part B-2 under Data and Results.

(2) Next determine the resistance of the regulating coil by connecting the wires at 1 and 2. (Slide No. 545.) Put a sheet of mica between the carbons. Record results as in Part B-2 under Data and Results.

(3) Find the resistance of the "ballasting coil" by connecting at 3 and 4. Record results as above.

(4) Measure the resistance of the electro-magnet and ballasting coil when connected in series, as at 1 and 4. Record the data.

Part C. (1) Use insulated cable to connect the lamp and rheostat in series to the power terminals. See that fuses are in circuit. HAVE THE CONNECTIONS APPROVED BY THE INSTRUCTOR BEFORE THROWING THE SWITCH, AND USE COLORED GLASSES WHILE WORKING WITH THE ARC. Study the arc by throwing its enlarged image (by means of a lens) upon the wall. Determine which carbon is plus, and arrange connections so that the upper carbon is positive.

Part D. (1) Trace the current through the plus terminal, through the rheostat and draw a sketch to show how you intend to connect the ammeter and voltmeter to measure the power (product of amperes and volts) used by the rheostat. See that the pointers on the instrument stand at zero before throwing the switch. Read the ammeter and voltmeter (interpolate to tenths of a scale division) every thirty seconds for the first four minutes, then every minute for four minutes. Make a record of the readings as shown under Data and Results.

(2) Next turn off the current and attach the plus wire of the voltmeter to 1 and the minus wire to 2, to measure the power consumed by the regulating coil. Leave the ammeters in series in all these tests. Take the readings as before and record them. MAKE SURE THAT ALL CONNECTIONS ARE SECURE. Record the measurements.

(3) Determine the power lost in the ballasting coil by connecting the voltmeter at 3 and 4. Take the same number of readings as above and record them. The positive terminal is connected to 3.

(4) Connect the positive terminal of the voltmeter at 4 and the negative binding post at 5. Find the power used by the arc. Make and record reading as in I.

(5) Shunt the voltmeter around the terminals of the lamp at 1 and 5. Find the power used by the arc, ballasting coil and electro-magnet.

(6) Finally, determine the power used by arc lamp and rheostat by connecting voltmeter in shunt across power terminals. What relation exists between (2), (3), (4) and (5)? Between (1), (2), (3), (4) and (6)?

## PART E.—QUESTIONS AND PROBLEMS

### Mechanics:

(1) What types of pulleys are found in the lamp?
(2) Name the special cases where friction is made use of to operate part of the mechanism.
(3) What application is made of the compressibility of gases in the "dash-pot?"
(4) Name the kinds of levers used in the lamp.
(5) What is the use of the counterpoise and how does it illustrate the principle of moments?
(6) Make a list of the different substances used in the lamp and name one property of each that causes the material to be used in the lamp.

### Heat:

(1) Why is there a deposit on the under side of the heat screen?
(2) Where are convection currents found?
(3) Name some parts that are heated by conduction. Some by radiation
(4) Trace the transformations of energy from the burning of coal to the electric arc.
(5) What is the highest temperature of which you know? What is the temperature of the arc? How is it measured?
(6) Estimate the total per-cent. of energy of the lamp that is "lost" by processes of heating. How many watts are "lost" in the electro-magnet? In the resistance coils? In the rheostat? In the ballast coil?
(7) Why will the inner layers of the magnet winding get hotter than the outer layers?
(8) How would you determine the "working temperature" of the resistance coils?
(9) What are the advantages and disadvantages of open and closed arc lamps? (See American Hand Book for Electrical Engineers.)*

### Sound:

(1) What causes the "singing" of the arc?
(2) Consult the above references on the so-called "musical arc."

### Electricity and Magnetism:

(1) Why are the resistance coils wound on a mica-asbestos tube?
(2) What is used to insulate the circuit from the iron frame?
(3) Where is porcelain used? Why?
(4) What kind of insulation is used on the wires?
(5) What is "horn fibre," "friction tape," "empire tape?"
(6) Make a list of all the conductors used in the lamp.
(7) What is the purpose of the adjustable resistance on the resistance coils?
(8) Why is the upper end of the positive carbon plated with copper?
(9) How is copper plating accomplished?
(10) Why does the iron core enter the magnet when the current is turned on?
(11) What kind of iron is best adapted for the iron core?
(12) Explain what is meant by each member of the equation $u = \frac{B}{H}$
(13) How would you measure the hot resistance of the "ballast?"
(14) Knowing the hot and cold resistance and the change in temperature, how could the temperature coefficient of resistance be found?

* 1914 Edition, John Wiley & Sons, Publishers.

(15) Explain how the electro-magnet controls the distance between the carbons.
(16) What causes the variation of current used by the lamp?
(17) Draw a diagram showing the shape of the magnetic field about the rings 2-3.
(18) Trace the direction of the current in the electro-magnet and diagram the field. Test the magnet with a compass to verify your conclusion.
(19) Is the resistance coil a magnet? How does it differ from the electro-magnet?
(20) What is meant by "ampere turns"? Find the ampere turns of the "ballast."
(21) Why is the positive carbon so much longer than the negative carbon?
(22) Account for the "cup" of the former and cone of the latter.
(23) At what angle from the arc is the light the most intense?

### Light:

(1) What are "cored" carbons? Why used? How is the light changed thereby?
(2) How does the light from the arc lamp differ in quality from that of a candle, gas-flame, incandescent lamp or the sun?
(3) What metal could be used for the arc? What kind of light would it give?
(4) What relation might be expected to exist between the amount of power consumed by the arc and the light given off?
(5) What kind of "spectrum" does the arc give?
(6) What is "ultra-violet" light?
(7) What will protect the eyes from such light?
(8) What is the average candle power of the electric arc? Calculate the watts per candle. On the basis of 10c. per kw.-hr. calculate the cost per c-p. hour.
(9) Calculate the cost of operating: (a) the rheostat; (b) the magnet; (c) "ballast;" (d) the arc; (e) the entire lamp.

### History of the Arc Lamp:

(1) Who made the first arc lamp? What was the source of power in this case?
(2) Whose name is always associated with the above scientist?
(3) Where was the first arc lamp exhibited in the United States?
(4) Relate some interesting incident concerning Ampère, Volta, Watt, Ohm and Coulomb.

### EXPERIMENT No. 10

# TESTING A FLAME ARC LAMP

(Lamp No. 2241)

Part A. (1) Diagram of regulating coil, resistance and arc lamp No. 2241.*

Part B. Resistance of Rheostat—4.18 ohms. (Average of 5 bridge measurements.) Resistance of Rheostat by volt-ammeter method—4.11 ohms.

Part C. Describe a good method to determine which power terminal is positive.*[2]

Part D. Diagram showing connections of voltmeters and ammeter for power measurements on rheostat. (See Slide No. 545.)

(1) Power consumed by rheostat—201.3 watts (mean of 12 readings).
(2) Power used by the regulating coil—21.5 watts (mean of 11 tests).
(3) Power required for the ballasting coil—224.4 watts (mean of 12 readings).
(4) Power used by the electric arc—277 watts (mean of 12 readings).
(5) Power consumed by arc, ballast and regulator—555.3 watts (mean of 11 readings).
(6) Power required to operate entire lamp and rheostat (obtained by volts × amperes method) 739 watts (mean of 5 tests).

PERFORMED BY: MACK KOWALEWSKI. Date: Oct. 27, 1914.

* The diagrams and sketches were so unusually well prepared and executed that we reproduced one of them without corrections or changes. Lack of space, however, obliged us to omit the others and also prevented us from giving more than a summary of the experimental work.—COMPILER.

*[2] Omitted by the student.

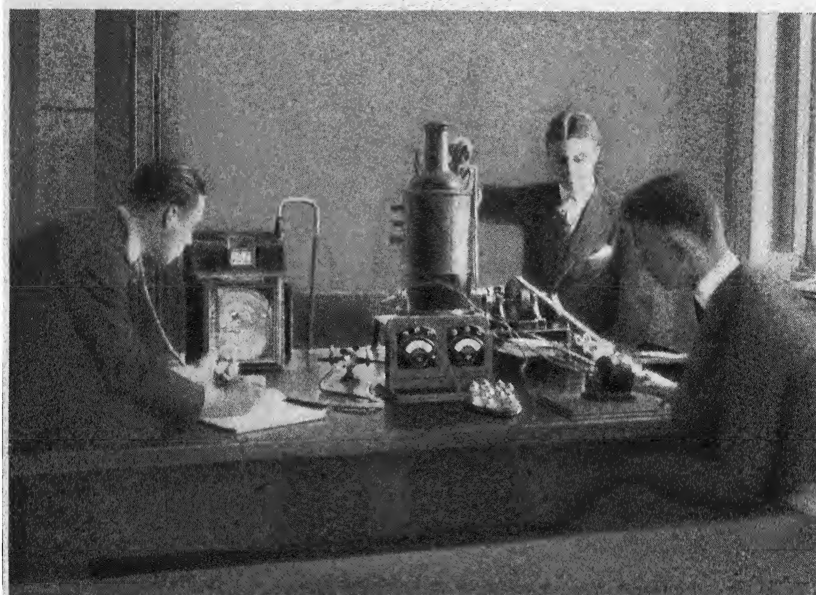
EXPERIMENT No. 11

# A SERIES OF POWER AND EFFICIENCY DETERMINATIONS

BY

FLOYD L. DARROW

HEAD OF SCIENCE DEPT., THE POLYTECHNIC PREPARATORY SCHOOL, BROOKLYN, N. Y.



Slide No. 546
Efficiency Test of a Small Power Plant

In our laboratory we have a small model power plant, consisting of boiler, steam engine and dynamo. The boiler has been tested to 200 lb. pressure and maintains about 65 lb. pressure when under load. At this pressure the engine develops about one-tenth horse power as determined by the brake test. The laboratory is also equipped with a one-half horse power, two-cycle gas engine, a gas meter and a modified form of Junker calorimeter supplied by the Central Scientific Company. With this equipment the students, all boys, working in groups, made the following determinations:

I. Horse power of the engines (brake test).
II. Heat value of the gas in B.T.U. per cubic foot.
III. Fuel efficiencies of the engines.
IV. Electrical efficiency of the power plant.

The data for the determination of the horse power of the steam engine follows:

OBSERVATIONS

| | I. | II. | III. | Aver. |
|---|---|---|---|---|
| Average pull on balance | 16 oz. | 16 oz. | 16 oz. | 16 oz. |
| Time in seconds | 60 | 60 | 60 | 60 |
| Number of revolutions | 570 | 570 | 540 | 560 |
| Length of brake arm | 12 in. | 12 in. | 12 in. | |

## CALCULATIONS

| | |
|---|---|
| Circumference of brake arm circle | 6.28 ft. |
| Average R.P.M. | 560 |
| Number of foot lbs. of work per rev. | 6.28 |
| " " " " " " " minute | 3516.8 |
| Horse power of engine | 0.104 |

This determination, together with one on the horse power of the gas engine, is made early in the year during the study of work and energy. Although the engines are not large, yet the pupil gets the method of measuring work and power and a much more definite idea of the concrete meanings of these terms than he can without such determinations. Furthermore, the pupil is immensely interested in this kind of work.

The second determination in the series, that of the heat value of the gas supply, is made during the study of heat. For this the gas meter, Junker calorimeter and a large catch bucket are used. The data for one set of determinations follow:

## OBSERVATIONS

| | I. | II. | III. |
|---|---|---|---|
| Temperature of inflowing water | 12.3°C | 11.5°C | 11.7°C |
| Average temperature of outflowing water | 21°C | 23°C | 24°C |
| Number of cu. ft. of gas burned | 0.75 | 1 | 1 |
| Weight of catch bucket | 2 lb. | 2 lb. | 2 lb. |
| " " " " and water | 28 5 lb. | 30 lb. | 27.5 lb. |

## CALCULATIONS

| | I. | II. | III. |
|---|---|---|---|
| Increase of temperature in deg. C. | 8.7° | 11.5° | 12.3° |
| Equivalent value in degrees F. | 15 7° | 20 7° | 22.1° |
| Number of lbs. of water used | 26.5 | 28 | 25 5 |
| " of cubic feet of gas burned | .75 | 1 | 1 |
| " of B.T.U.'s of heat developed | 416 | 579 | 564 |
| " of B.T.U.'s of heat per cu ft | 555 | 579 | 564 |
| Average " " " " " " " | 566 | ... | .. |

The student then, in addition to explaining the method, calculates the number of cubic feet of gas that would be equivalent to one ton of coal of some specified heat value and compares the relative costs.

The third determination, that of the fuel efficiencies of the enignes, follows closely upon the preceding, after the students have studied the mechanical equivalent of heat. In these determinations the number of cubic feet of gas used in a definite period of time while the engines are under load is measured. Then from the known horse power of the engine and the heat value of the gas, as already determined, together with the mechanical equivalent of heat, the student works out the ratio between the work done by the engine and the energy input. It should be stated that each group of boys makes but one determination, and the results of the different groups are compared. A set of determinations for the steam engine follows:

## OBSERVATIONS

| | I. | II |
|---|---|---|
| Time in minutes | 5 | 5 |
| Number of cubic feet of gas burned | 3 | 3 |
| Horse power of engine | 0.10 | |
| Heat value of gas | 566 B.T.U's. | |

## CALCULATIONS

| | |
|---|---|
| Number of B T.U's. in gas used | 1698 |
| " of foot lbs. of energy used | 1321044 |
| " " " " " " per minute | 264209 |
| " " " " " work done " " | 3300 |
| Efficiency of boiler and engine | 1.2% |

At the same time the fuel efficiency of the gas engine is also determined and the reasons for its higher efficiency are considered. By examination of the engines while in operation, the student tries to discover as many causes as possible for the enormous loss of energy, and right here comes one of the chief values of this sort of work. You may tell a boy of the

energy losses in a power plant, but he does not really or intelligently appreciate their magnitude until he has carried through a series of determinations himself.

The final determination of the electrical output of the plant may follow here or be left until the subject of electrical power is taken up. In this work a dynamo is run by the engine and the current generated is used to light a circuit of six small lamps. A Weston voltmeter and ammeter are used to determine the number of watts delivered. In this work, too, a rheostat is substituted for the lamp board and the results of varying the resistance both upon the speed of the engine and upon the voltmeter and ammeter readings are observed. Following is a set of readings obtained with the rheostat in circuit:

### OBSERVATIONS

| | I. | II. |
|---|---|---|
| Number of volts | 6 | 6 |
| " " amperes | 5 | 5 |
| Horse power of engine | 0.10 | |
| Fuel efficiency of boiler and engine | 1.2% | |

### CALCULATIONS

| | |
|---|---|
| Number of watts delivered by dynamo | 30 |
| Power input of engine in terms of watts | 74.6 |
| Electrical efficiency of engine and dynamo | 40% |
| Final fuel efficiency of plant | 0.5% |

Although the efficiencies as shown by determinations are low, yet this is to be expected with a small plant. The determinations in the foregoing set follow each other in logical sequence. They command the boy's keenest interest and are by no means too difficult for his understanding. They help him to see definite and useful purposes in the study of physics.

Although this work is full of mathematical calculations, yet the student finds no drudgery in them, for he is solving definite and interesting problems of his own making. Such work will go far toward robbing physics of any mathematical terrors which it is frequently thought to possess.

Performed by
CHARLES J. PARSONS,
FOREST M. TOWL, Jr.,
KENNETH M. COLLINS.

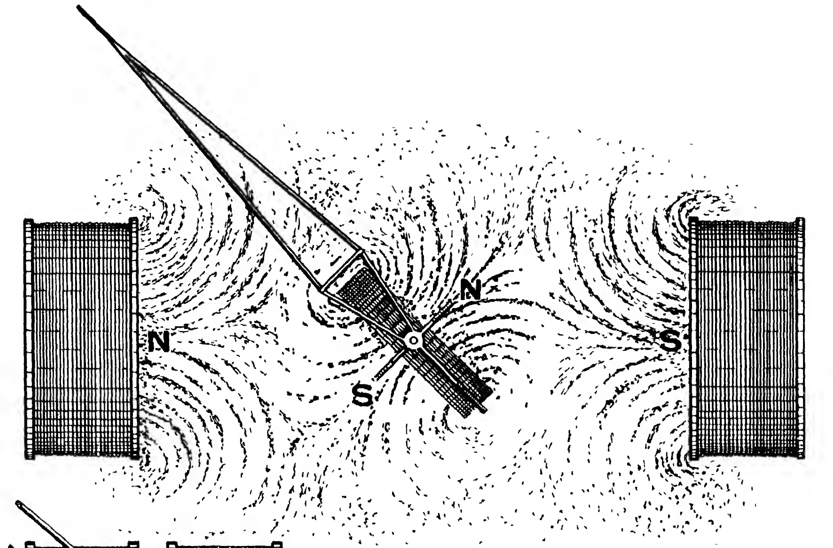
### ELECTRO-DYNAMOMETERS

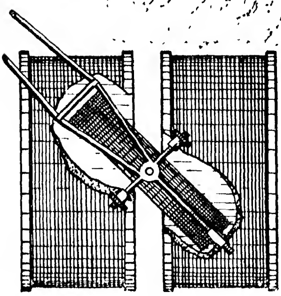
You will remember—Ampère discovered that two conductors through which current was flowing would attract or repel each other. Also, do not forget that Joseph Henry constructed powerful electromagnets by winding insulated copper around iron cores.

The iron core is necessary if we want to make an electromagnet, but the coil alone, without iron, acquires magnetic properties when a current is sent through it and in addition will have a strong and well-defined magnetic field. This fact has been utilized in the construction of certain types of measurement apparatus known as electro-dynamometers. These were at first of the suspended-coil reflecting-mirror variety, and later were made portable, but the principle was the same in all of them, namely, to establish a magnetic field by means of one or more coils, and to place in or near this field a movable coil through which current could flow, in order that its polarity would cause it to rotate.

The Weston portable dynamometer instruments include ammeters, voltmeters and wattmeters, as well as many special models for switchboard and laboratory use.

To demonstrate the lines of force, the field coils and movable coil of a Weston a. c. voltmeter were connected together in series and mounted on a board, the field coils being intentionally separated a considerable distance from each other, so that their magnetic lines, and those of the movable coil



Slide No. 547
Magnetic Field of a Weston
Electro-dynamometer

could be outlined individually. These lines were then portrayed by Faraday's well known method as follows: A piece of drawing paper was impregnated with paraffine, and mounted on a frame. Holes were made, through which the coils projected to their centers. Very fine iron filings were then sifted over the surface of the paper. Then the current was passed through all three coils simultaneously.

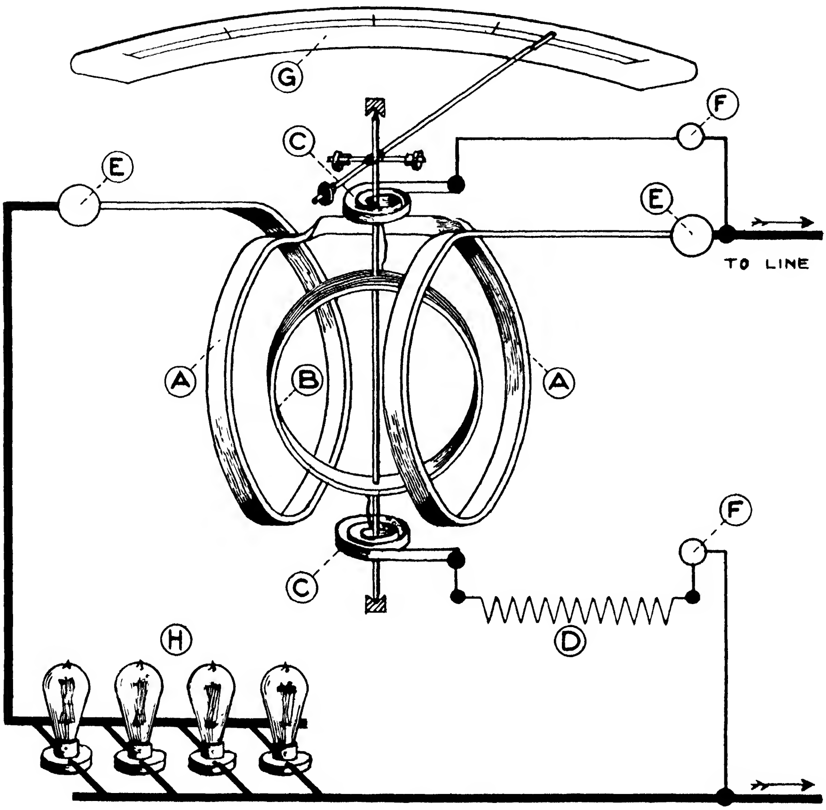
The filings at once arranged themselves almost as shown, but a slight tapping on the paper improved and concentrated the lines. The chart was then made permanent by softening the paraffine with a piece of hot metal.*

When the movable coil is provided with a pointer and scale, and is mounted on a support between the field coils, the latter being close together, as shown on the lower picture, the instrument may be calibrated for either direct or alternating current. A properly constructed and adjusted resistor is also necessary to limit the current, precisely as in direct current instruments.

For practical measurements with direct current, the dynamometer type of voltmeter has no advantages over the permanent-magnet instruments, and has some disadvantages, chief among which is its lack of uniformity in scale divisions. It is, however, of great value for alternating current work, because its field and movable coil may be magnetized, demagnetized and remagnetized by means of alternating current, and the successive impulses which the movable coil will receive in this manner will cause it to rotate, and the pointer will indicate the alternating potential which is being tested.

* Iron should not be used for this purpose, since it tends to disarrange the filings.

## WATTMETERS




Slide No. 548

Scheme of a Weston Wattmeter

In order to understand wattmeters, you will have to familiarize yourselves with the electrical unit known as the **Watt** and named in honor of James Watt * of steam engine fame. The watt is the unit of electrical power. It is the product of volts multiplied by amperes. It represents the mechanical equivalent of electrical power. One watt is equal to $\frac{1}{746}$ of a horse power.

Wattmeters are of two types, recording and indicating. Recording meters record the total power consumed, indicating wattmeters are designed for the rapid and accurate determination of any load, and are also extensively used for checking recording wattmeters and watt-hour meters.

Weston indicating wattmeters are constructed on the dynamometer principle, in order that they may be operative with either direct or alternating current.

Their essential parts are one or two field coils, a pivoted movable potential coil, a series resistor, a spring control and an index.

* 1736-1819

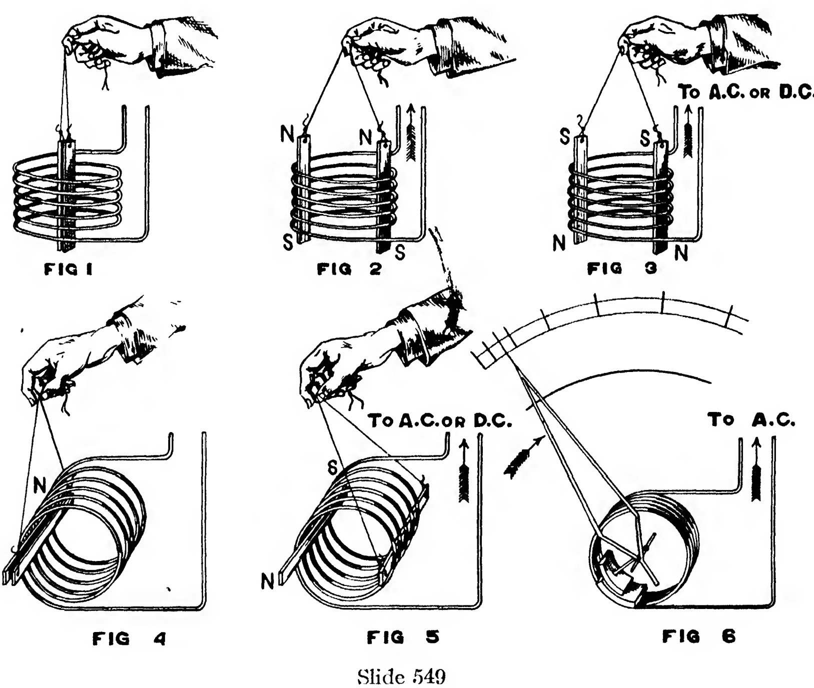
The principle of construction is as follows: (Slide No. 548)

The field (A) is made of two coils having dimensions which will permit the entire current to flow through them without raising their temperature appreciably. The movable coil (B) is pivoted in jeweled bearings and consists of a number of turns of fine insulated copper or aluminum wire. The spiral springs (C) serve as current conductors, and control the movement of the coil.

To regulate the current through the movable coil, an adjusted resistor (D) is connected in series with it. This resistor is wound non-inductively, and is made of high resistance alloy wire having a negligible temperature coefficient.

The operation of the instrument is as follows: The current terminals (E) are connected so that the entire current flowing through the load (H) and fixed coils (A) produces a magnetic field. Another field is obtained by connecting the movable coil and its resistor **across** the line by means of the potential terminals (F). The movable coil will then rotate in order to reduce the distance between the opposite polarities of these fields. Since the strength of one field depends upon the "load current" and since the other current flowing through the movable coil depends upon the voltage of the line, the instrument indicates the effect of amperes × volts = **watts,** and the scale (G) is accordingly calibrated in watts, so as to be direct reading.*

THE WESTON MOVABLE IRON SYSTEM




Slide 549
The Principle of the Weston Movable Iron Repulsion Instrument

* See also "Household Physics." Butler, p. 258

It is of course a well known fact that instruments of the movable coil type having a permanent magnetic field cannot be operated with alternating current, since continuous torque in one direction is not obtainable under the conditions.

In an earlier lecture we referred to a type of instrument in which the movable element consisted of an iron rod which was sucked into a solenoid when current was sent through the latter.

Instruments operated on this principle, although faulty in design and erratic in their indications, have one characteristic which entitles them to consideration, which is that they are operative with both direct and alternating current.

It is, however, possible to produce an instrument in which the defects of the solenoidal apparatus are eliminated and results obtained of a high degree of accuracy by means of a light movable iron operated by magnetic repulsion.

This is the principle upon which the Weston movable iron instruments are operated, which can be readily understood by reference to Slide No. 549. Fig. 1 shows two small pieces of iron suspended vertically within a solenoid by means of threads. If a direct current is sent through the solenoid, the two iron rods will become magnetized, and since they are in the same magnetic field, they will both be affected precisely the same. Hence each will have (let us say) a North pole at the upper end and a South pole at the lower, and since like poles repel, they will, of course, fly apart (Fig. 2). If the circuit is then broken, they will lose their magnetism and resume their original positions. If the current is now sent through the solenoid in the opposite direction, the effect will be the same as before, because (Fig. 3) both bits of iron, although now magnetized with opposite polarity to what they were at first, continue to repel each other.

If next the solenoid is laid on its side, and the two bits of iron are placed within it horizontally (Fig. 4) one of them being fixed and the other free to move, the conditions will be substantially the same as before, and if (Fig. 5) current is now sent through the solenoid, the suspended iron will tend to repel the fixed one and will be repelled by it.

And if an alternating current be used instead of a direct, and it reverses with sufficient frequency, the polarities of the fixed and suspended bits of iron will reverse correspondingly, and the movable iron will be continuously repelled.

It is now easy to understand the operation of the instrument (Fig. 6). All that is necessary is a piece of iron of the proper size and shape fixed in place and having a curved surface. Another bit of iron is pivoted so that in order to escape from the fixed iron, it must rotate, that being its only possible motion.

The extent of rotation depends upon the strength of the magnetic field, which in turn depends upon the current flowing.

Of course, in order to obtain practical and uniform results, voltmeters and ammeters based upon this principle have to be constructed with great care. Among other details, the size, shape and treatment of the iron parts are of the utmost importance so that they may become magnetized and demagnetized without errors due to hysteresis or lag.* .

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* A further description of these instruments, together with phantom views of their parts, will be found in Monograph "B-4." See "The Weston Alternating and Direct-Current Soft-Iron System."

# THE DIRECT CURRENT WATT-HOUR METER

BY

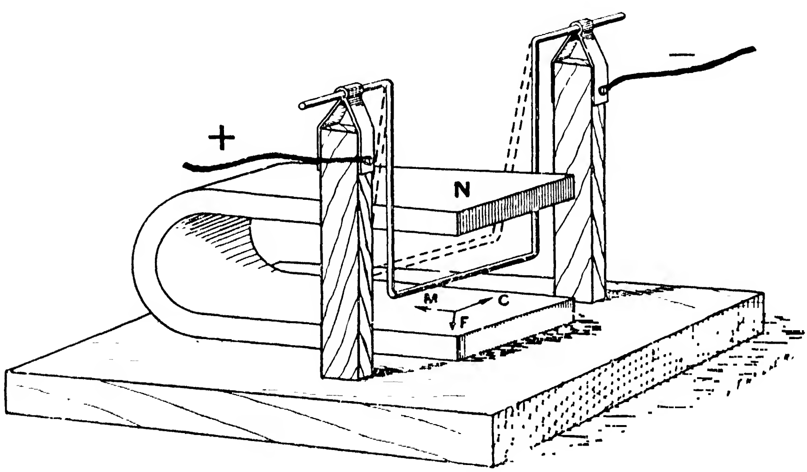
HOWARD W. MOTT

MEMBER OF THE PHYSICS AND ENGINEERING STAFF OF THE STUYVESANT HIGH SCHOOL, CITY OF NEW YORK

## WATT-HOUR METERS

It is well known that electrical energy is paid for by the kilowatt-hour; one kilowatt-hour being the quantity of electrical energy consumed when power is used for one hour at the rate of one thousand watts. The watt-hour meter (since it adds up the work done at all instants) is used to measure this electrical energy.

The Thomson meter is a form which has been employed for many years with success. It is primarily a small motor, the armature of which revolves at a speed proportional to the rate at which electrical energy is passing through it.




Slide No. 550
Experimental Illustration of the Motor Principle

The principle on which the direct current motor operates is readily understood from such an experiment as is now shown. Note that the supported wire moves in the magnetic field as indicated when a current is passed through it. Fleming's "left hand rule" may be demonstrated here.

If we counter-balanced the wire shown in the picture, and modified its size and shape so that the supports from which it hangs would be half-way between the magnetic poles instead of above, then the wire would make a half revolution with the current as indicated.

By adding a commutator to reverse the current direction at the end of the swing, continuous rotation would result if it could make a complete

revolution. The reason the wire moves is that lines of force are developed around it when the current flows, and these lines re-act with the field of force maintained by the magnet, and produce a force to move the wire. If the wire is arranged to rotate, this force produces a torque.

The field of the Thomson watt-hour meter is produced by current in the stationary coils which are in series with the line. There being no iron in the field, the field strength is proportional to the current flowing in the main line. The armature is connected by means of a commutator across the line so that the current in the armature is proportional to the voltage across the line.

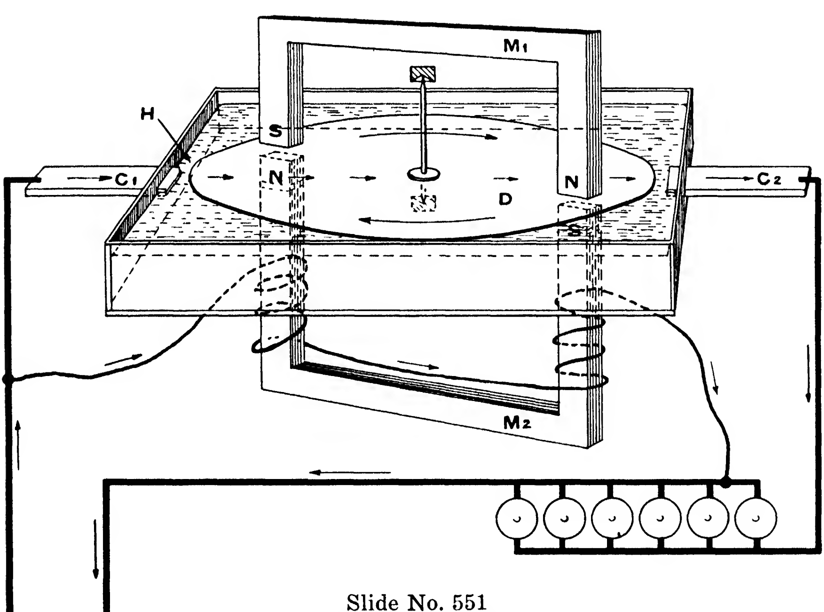
The torque then must be proportional to the product of the voltage and the current, or the watts in the line.

The friction is reduced to a minimum by means of jeweled bearings. Since there is no iron in the magnetic circuit, the field is weak, and therefore no counter e.m.f. of any appreciable value is set up by the rotation of the armature, so that the current through the armature is proportional to the voltage of the line.

## THE SANGAMO DIRECT CURRENT WATT-HOUR METER

The Sangamo meter is a recent development, and very cleverly avoids many difficulties of former meters.

The Sangamo watt-hour meter, by a very ingenious use of mercury as a fluid conductor, effects an exact reversal of the conductor arrangements




Slide No. 551
Principle of the Mercury Motor

usually employed and at the same time does away with the usual commutator and brushes. Referring to the diagram (Slide No. 551), a practically constant magnetic field is produced by the electromagnet, $M_1M_2$ connected across the line. Its strength is proportional to the voltage. Whenever lamps, etc., are turned on, current from the line flows in at $C_1$, through the mercury H, through the copper segmental disc D on a diameter, again through the mercury and out at $C_2$, going on through the lamps and back to the generator on the return wire. Since the current goes through the disc at right angles to the flux, it sets up magnetism in the disc, which acts with the permanent flux of the voltage coils to produce rotation. Since the disc rotates in mercury, which is a conductor of electricity, there is no need for a commutator and brushes, the disc acting as its own commutator and the mercury as the brushes. Also, since the disc is arranged with a float to ride in the mercury, the bearing friction is practically zero. The function of the bearings becomes that of merely guiding without the necessity of supporting the weight of the moving element. The friction in the mercury itself is viscous in character and extremely small, at the speeds used in these matters.

It is a notable fact that mercury is a much poorer conductor of electricity than copper. Thus it is that the current on entering the disc chamber goes mainly through the copper disc on its diameter rather than through the surrounding mercury.

Since a meter will start with only a small fraction of the total load it can register, it is obvious that the meter would "race" with any ordinary load if there were no retarding torque applied to it.

The necessary retarding torque is established by compelling the motor to drive a short-circuited generator, thereby obtaining an electro-dynamic retarding torque, which is always proportional to the speed of the armature and balances the torque developed. In all types of watt-hour meter this action is secured by attaching a light metal disc (usually of aluminum) to the revolving element and arranging it to rotate between the poles of moderately strong permanent magnets. (See Slide No. 554, Fig. 4.) Whenever it revolves eddy currents are set up in this disc, which re-act with the magnetic field of the permanent magnet, so as to produce a "braking action." The strength of these eddy currents, and consequently of this braking action, is directly proportional to the speed. Thus the torque of the motor portion of the meter is held in check by the electro-dynamic retarding torque of the generator action of the magnets and disc.

In order to record the energy, the shaft of the motor is connected with dial hands by means of gears. These dials register the number of kilowatt-hours of energy which have passed through the meter.

Various adjustments of current through the voltage coils and of magnetic strength are necessary, in order to compensate for errors. These have no place in a discussion of general fundamental principles.

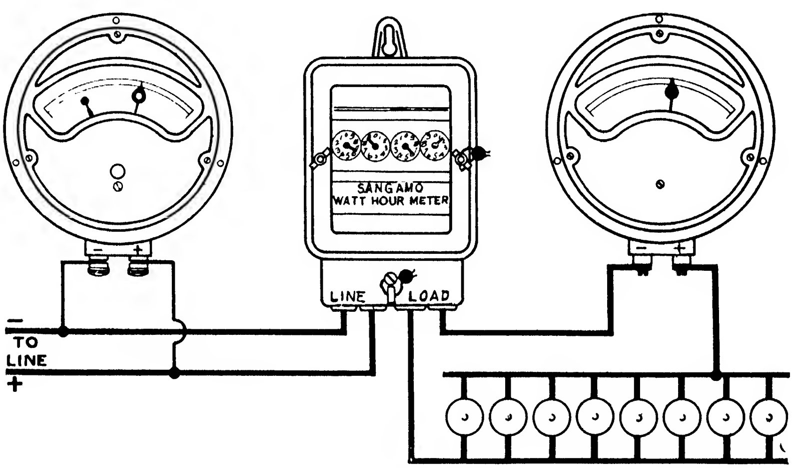
## EXPERIMENT NO. 12

# TESTING A SANGAMO DIRECT CURRENT WATT-HOUR METER

PERFORMED UNDER THE DIRECTION OF

MR. HOWARD W. MOTT

INSTRUCTOR IN APPLIED ELECTRICITY, STUYVESANT HIGH SCHOOL
CITY OF NEW YORK

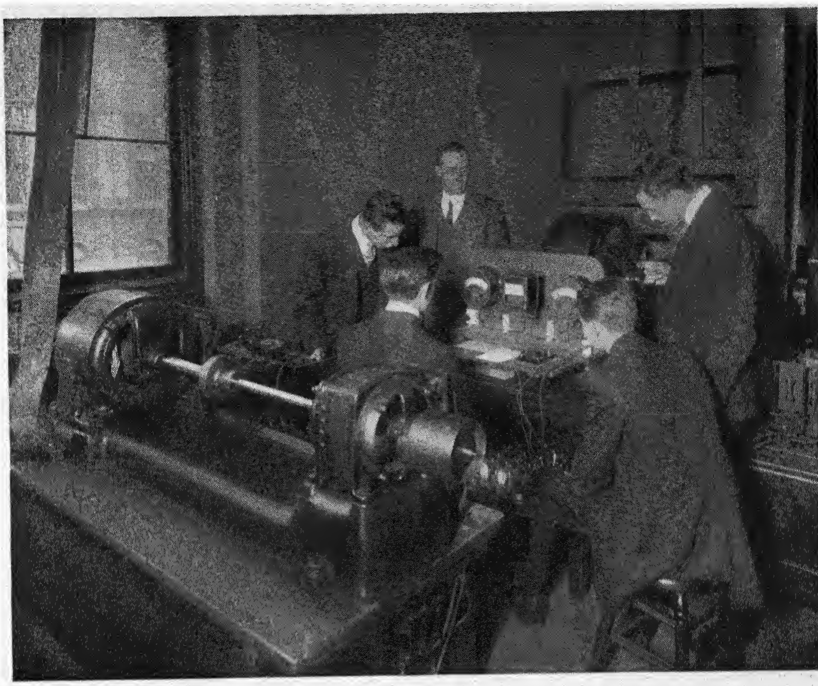



Slide 552
Connection Diagram for Testing a Sangamo Direct Current Watt-Hour Meter with Weston Indicating Instruments

The main fact usually sought in testing a watt-hour meter is the accuracy of the instrument, i.e., the relation between its indicated watt-hours and the actual watt-hours.

This difference, if any, is usually expressed as a percentage error. It is also necessary to ascertain if this error varies with the load or is independent of it.

Meters are also often tested to ascertain whether or not there is any "creeping," i.e., very slow rotation of the revolving element without any current flowing through the line, due to overcompensation; or, if there should be no creeping, a "minimum current test" is applied to ascertain the minimum current at which the meter will start.



Slide No. 553
Testing a D. C. Watt-hour Meter

Creeping causes the customer to be overcharged, whereas a slow meter results in an undercharge. When errors are found, the meter case must be opened and various adjustments made with a subsequent set of readings taken in each case until the error is corrected or minimized.

The following "outside" or "sealed meter" test and minimum current test were run at the Stuyvesant High School by students ranging in age from fifteen to twenty years.

Connections as shown were made, wherein attention may be called to the fact that the ammeter is so placed that it reads only the current furnished to the load and not that necessary to operate the voltmeter and the voltage circuit of the watt-hour mter. It is only with such a circuit as this that just ratings may be made.

Four students worked at a time with duties as follows: Student 1. Time announcer, using a stop-watch and announcing half-minute intervals. Student 2. Tallier, counting watt-hour meter disc revolutions with an electric counter; i. e. a telephone service meter in circuit with a battery and strap key. Student 3. Voltmeter reader, reading and recording voltmeter at called intervals. Student 4. Ammeter reader, reading and recording ammeter at called intervals.

Several sets of readings at each load were taken, of which the following table is a sample:

| Time in Minutes T | Current I | Voltage E | Watts W | Rev. Counter Reading, R |
|---|---|---|---|---|
| 0.00 | 5.9 | 105.0 | 619 | 3602 |
| 0.5 | 5.9 | 105.0 | 619 | |
| 1.0 | 5.9 | 105.0 | 619 | |
| 1.5 | 5.85 | 105.5 | 617 | |
| 2.0 | 5.85 | 104.5 | 612 | |
| 2.5 | 5.85 | 104.5 | 612 | |
| 3.0 | 5.85 | 105.0 | 614 | |
| 3.5 | 5.85 | 105.0 | 614 | |
| 4.0 | 5.85 | 105.0 | 614 | |
| 4.5 | 5.85 | 105.0 | 614 | |
| 5.0 | 5.80 | 104.5 | 607 | |
| 5.5 | 5.80 | 104.5 | 607 | |
| 6.0 | 6.0 | 105.0 | 630 | |
| 6.5 | 6.0 | 104.0 | 624 | |
| 7.0 | 6.0 | 104.0 | 624 | |
| 7.5 0.6 Sec | 6.0 | 104.0 | 624 | 3718 |
| | | | 16 \| 9870 | 116 |
| | | | Average Watts, 617 | Total Revs. |

Calculations were made as follows:

Actual watt-hours = **E·I·t** (in hours)

Indicated watt-hours = **r** (of disc in $\frac{2}{3}$ time, **t**)

$$\% \text{ Error} = \frac{\text{Actual watt-hours} - \text{Indicated watt-hours}}{\text{Actual watt-hours}} \times 100$$

Or, for the table of readings shown as a sample:

$$\text{Time in hours} = \frac{15}{2} \times 60 + \frac{6}{10} \times \frac{1}{60 \times 60} = 0.1252 \text{ hours.}$$

Actual watt-hours = average watts × time = 617 × 0.1252 = 78.2.

Indicated watt-hours = **r** × $\frac{2}{3}$ = 116 × $\frac{2}{3}$ = 77.3.

$$\text{Error} = \frac{78.2 - 77.3}{78.2} = \frac{0.9}{78.2} = 0.0115$$

% Error = 0.0115 × 100 = 1.15 slow.

A table of the average results with different loads is given below:

| Time of run. | | Voltage | Current. | Watts. | Disc.Rev. | Watt-hours. Act. | Watt-hours. Ind'd. | % Error. |
|---|---|---|---|---|---|---|---|---|
| 6 Min. | 31.2 Sec. | 106.8 | 1.705 | 181.7 | 29 | 19.70 | 19.34 | 2.03 Slow |
| 7.5 " | 0.6 " | 104.5 | 5.875 | 617.0 | 116 | 78.2 | 77.3 | 1.15 Slow |
| 6.5 " | 0.0 " | 106.6 | 10.000 | 1072.0 | 171 | 116.1 | 114.0 | 1.70 Slow |

During the complete period of testing the watt-hour meter, the voltage was kept as nearly 105 as possible, this being the voltage for which the meter was adjusted before sealing. While some variation from this figure may be noted, at worst it was about 1.7% above proper value. This condition does not do entire justice to the watt-hour meter, and this fact should be taken into consideration in reading the table.

A minimum-current test was also run, using a very sensitive low-reading ammeter of the Weston Model 280 type, with the result that it required about ⅛ ampere as a minimum to start the disc from rest and a practically negligible amount to maintain rotation after the disc was once started; this latter current being so small that the meter needle gave merely the faintest flutter upon closing and opening the circuit.

Performed by

HARRY C. KEIL — W. DOUGLAS GRAY

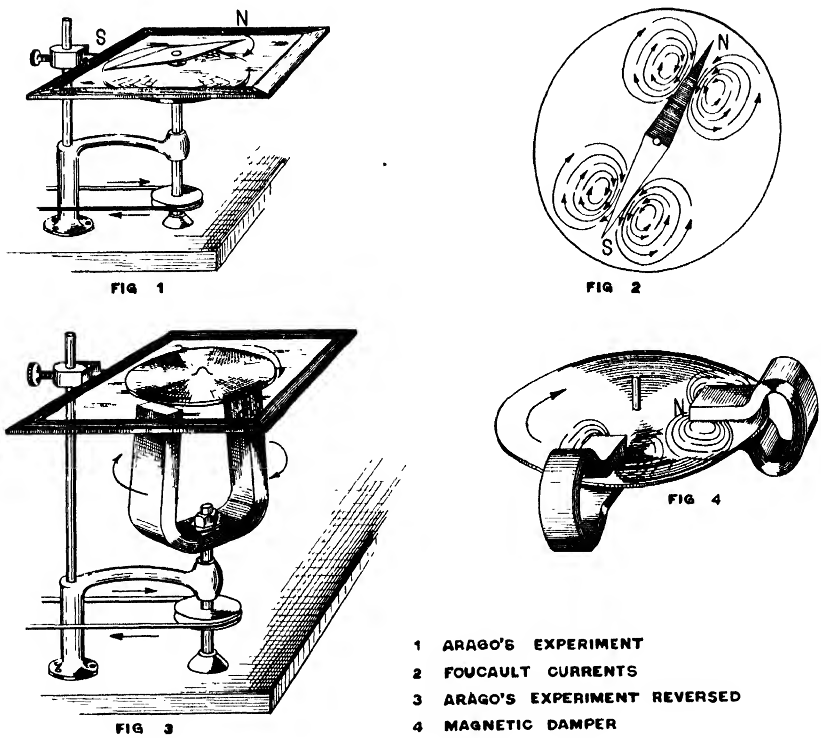
HERBART HARTMAN — NEWTON KURTZE

# THE ALTERNATING CURRENT WATT-HOUR METER

BY

ERNEST REVELEY SMITH

VICE-PRINCIPAL, NORTH HIGH SCHOOL, SYRACUSE, N. Y.




Slide 551
Induced Currents

The Sangamo Type H watt-hour meter is an induction meter. It is a highly specialized form of the split-phase induction motor. The induction motor is a natural outcome of the experiment of Arago (Fig. 1), which later was reproduced and explained by Faraday. In this experiment a magnet is suspended horizontally over a copper disc supported on a vertical axis. When the disc is rotated, the magnet, if free to move, will turn in the same direction. If, on the contrary, the magnet is rotated (Fig. 3), the disc will rotate but with a somewhat slower speed. These results are due to induced currents produced in the disc and known as eddy or Foucault currents. (Fig. 2.) If a copper or aluminum disc is made to rotate so that

its edge passes between the poles of an electromagnet, it appears to meet with sudden resistance when the current is turned on through the magnet. Foucault explained this action by showing that eddy currents exist in that part of the disc passing the poles of the magnet and that these currents hold the disc back. It has been shown, also, that the drag due to these eddy currents is proportional to the speed of the disc and to the square of the strength of the magnetic field. Hence with a field of constant force, as one produced by a permanent magnet (Fig. 4), the drag is proportional to the speed of the disc. This drag on the disc, then, keeps the speed proportional to the force producing the rotation, or the torque, as it is called.

It remained for Professor Ferraris in 1888 to discover the connecting link between an electrical toy—Arago's disc—and a commercial machine of immense everyday value—the induction motor. Arago rotated his magnet bodily and the disc followed; Ferraris discovered that a rotating field may be produced from stationary coils by means of polyphase alternating currents. Remember that an alternating current increases from zero value to a maximum value in a positive direction, decreases to zero, then to a maximum value in a negative direction and finally increases back to zero—four steps or one cycle in all. One of these steps, say from zero to positive maximum value, is a quarter of a cycle. Imagine two conductors running side by side. Also imagine a current beginning to increase from a zero value on one of these conductors just as a first current, started over the other conductor an instant before, has begun to decrease from a positive maximum value. These currents will traverse the conductors and will keep a quarter of a cycle apart. Taken together, with the necessary return wires, these two currents are called two-phase alternating currents.

Now two-phase alternating currents may be made to produce a rotating magnetic field in a motor by proper winding of the field magnet with the wires carrying the two currents. In this field the north and south poles will rotate from coil to coil of the field magnet, making one complete rotation for each complete cycle of the current.

The rotating magnetic field may also be produced by a single-phase current, providing alternate coils in the field are wound with different resistance and reactances to make the current through one of these coils retard or lag a quarter of a cycle or less behind the current in the other coil. This method of producing a rotating magnetic field is called the "split-phase" method. It finds application not only in starting devices for single-phase motors, but largely in single-phase watt-hour meters.

The Sangamo alternating-current watt-hour meter has, for a rotor, a light aluminum disc securely mounted on a brass shaft. This moving element weighs only 15.2 grams. It rests on a cup jewel for a bottom bearing, and has a long and somewhat flexible upper bearing. This consists of a highly tempered steel wire which is set into the top of the shaft and turns in a long "guide ring."

This disc rotates between the poles of one shunt and two series coils. The shunt coil is the potential coil. The series coils carry the current of the load that is to be measured. The inter-action of these three coils produces the rotating field and hence develops the torque that drives the rotor—the disc. Since the weight of the disc and shaft is small and the torque rather large in proportion, the ratio of torque to weight is large and so the meter starts on very small loads. The aluminum disc also passes between the poles of two permanent magnets. The eddy currents produced in the disc by the constant field of the magnets cause the rotor to move at a speed proportional to the torque, as explained above. Since the value of the torque

depends entirely upon the amount of power passing through the meter, the speed of rotation, therefore, is in a direct ratio to the power passing in the circuit. Hence one rotation corresponds to a definite quantity of electrical energy. In the meter described, one rotation of the disc represents 5/24 of one watt-hour. This number is the so-called "constant" of the meter, and is supplied by the makers of the meter and conveniently marked on the instrument. It is used in testing the accuracy of the meter.

The shaft carrying the rotating aluminum disc has a worm gear upon it. This gear drives a train of gears which in turn revolves the pointers on the dials. The train of gears is carefully made and so designed in its several wheels that the dials show watt-hours directly. The dials are usually four in number. They are divided into ten divisions and register progressively in ratios of ten, a complete rotation of the hand on one dial being equal to one division on the next higher dial, etc. The number of kilowatt-hours indicated by one scale division on the lowest dial depends upon the maximum load which the meter is designed to carry, called its ampere capacity. On the ordinary Sangamo house meter one scale division on the lowest dial usually represents one kilowatt-hour, on the next, ten kilowatt-hours, etc.

The watt-hour meter furnishes the basis for the much-denounced electric-light bill. Upon it depends the revenues of the various electric-power companies. The outgoing line is sent through a high-powered meter at the power house and later divided among the meters of the individual consumers. The sum of the small-meter readings added to the line and transformer losses, including the power consumed by the potential coils of these meters, ought to be equal to the reading of the meter at the central station. Any great difference between these amounts would show inaccuracies in the meters, leakages on the line, or theft of power.

The individual meters are read periodically and the bill rendered to the consumer for the difference between the present and last meter readings. Electric energy is sold to the small consumer at a flat rate per kilowatt-hour. To larger users of electricity the rate is decreased, the amount of such reduction depending upon the amount of power used and in some places upon the time of day it is needed. If the demand comes at a time when the power station is not on the peak of its load, the cost can easily be made smaller than in the case when it adds to an already large peak load.

The watt-hour meter indications represent dollars and cents as the pointers on its dials slowly rotate. Accordingly such an instrument must be reasonably accurate. If the meter registers low, it means loss of revenue to the company furnishing the electricity, and on the other hand, if it runs too fast it quickly produces dissatisfied customers—a condition just as bad for the company as the first.

In view of these facts, every large dispenser of electric power keeps a well organized meter-testing department. Upon this department rests the responsibility of keeping the entire system of meters up to a certain standard of accuracy. It is usually demanded that meters be adjusted to record the true energy within ±2 per cent. on non-inductive loads. The meter under discussion is guaranteed to have this degree of accuracy between 5% and 150% of full load. In the appended test, the meter showed a greater degree of accuracy than this. The Sangamo meter has a small auxiliary coil in connection with the shunt coil which is so designed that it produces proper phase compensation to make the meter nearly as accurate on inductive loads as on non-inductive loads. In fact the type H. Sangamo meters are

"guaranteed to record true energy at 50% power factor within ± 2 per cent. of the accuracy on non-inductive loads of the same amperes."

In order to maintain such degrees of accuracy, simple methods of adjustment must be supplied by the instrument makers. These, with short and accurate means of testing, put into the hands of the testing department the possibility of maintaining the accuracy of the entire system.

In the Sangamo meter the full-load adjustment consists of a small iron disc resting between the poles of the permanent magnets. This disc is carried on a micrometer screw. To make the meter run faster this disc is raised. Then some of the lines of force are shunted into the disc and away from the gap in which the aluminum disc moves. This decreases the retarding effect and hence the meter runs faster. Lowering the disc increases the number of lines of force in the gap, thereby increasing the braking effect and retarding the motion. These adjustments are made from the front of the meter when the cover only is removed.

The light-load adjustments are equally as simple and as easily made. A micrometer screw coming to the front of the meter turns a metal vane which lies in the shunt-coil gap. Turning the vane out of the center sets up an unbalanced effect which tends to turn the rotor either backward or forward, depending upon which side of the center the vane is placed. This adjustment is the one most used in meter regulation and is so sensitive that the meter may often be adjusted to 0.1 per cent. on one-tenth load.

The actual testing of a watt-hour meter requiries an accurate indicating wattmeter connected into the load side of the meter, as well as a suitable load—usually lamps (see Slide No. 555). The rate of the meter is tested by determining the number of revolutions of the disc in a suitable period of time. The time of one revolution is then computed and then the number of revolutions in one hour. This last number multiplied by the value of one revolution in watt-hours (the constant of the meter) gives the meter reading in watts. This value is then compared with the reading of the indicating wattmeter. The latter reading is assumed to be correct, and proper adjustments are then made until the meter rate is within the desired accuracy.

The entire method of testing depends upon the fact that the transmission gearing between the shaft and dials is positive in its action and each gear wheel moves in only one direction. Hence there can be no lost motion. If these gears were properly designed by the makers—an assumption that must be made—and if the rate of rotation of the disc is correct—determined by test—the meter must register accurately on its dials.

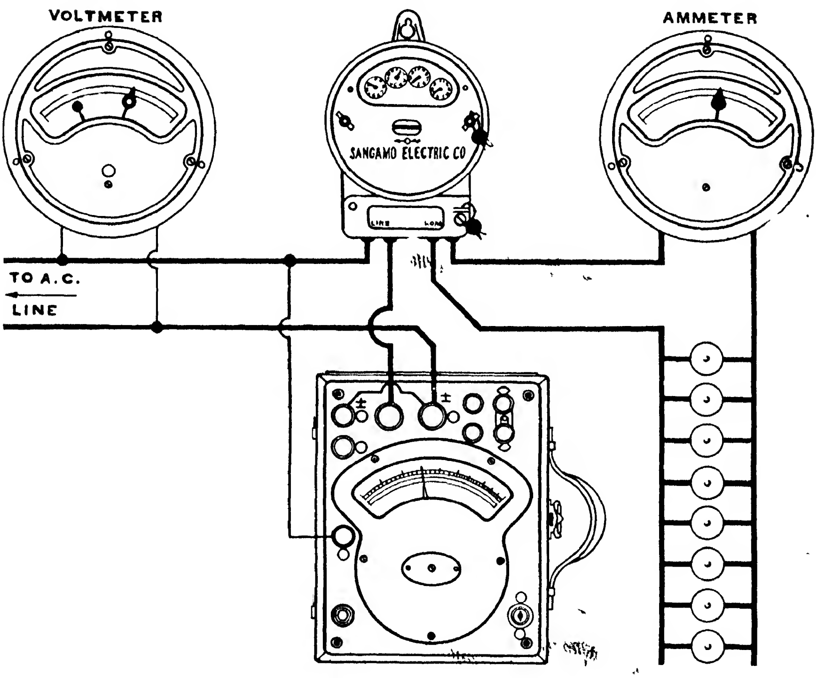
## EXPERIMENT No. 13

# TESTING AN ALTERNATING CURRENT WATT-HOUR METER

PERFORMED AT THE NORTH HIGH SCHOOL, SYRACUSE, N. Y.,
UNDER THE DIRECTION OF

## MR. ERNEST R. SMITH

VICE-PRINCIPAL AND INSTRUCTOR IN PHYSICS




Slide No. 555
Testing a Sangamo A.C. Watt-Hour Meter
with a Weston Indicating Wattmeter

PURPOSE: To test a Sangamo watt-hour meter.

APPARATUS: A single-phase type H Sangamo watt-hour meter; Weston Model 310 indicating wattmeter; Model 156 Weston a. c. voltmeter and ammeter; lamp bank; stop watch; and source of alternating current.

MANIPULATIONS: The instruments were connected as shown in the diagram. The observations were divided among the students, one reading the voltmeter, another the ammeter, the third the indicating wattmeter, and the fourth counting the revolutions of the watt-hour meter.

With a very light load, the revolutions of the disc of the watt-hour meter were counted for about five minutes and the readings of the other instruments taken every fifteen seconds.

Similar readings were taken with increased loads, until in the last case the maximum load for the watt-hour meter (5 amps.) was used.

COMPUTATIONS: We first computed the time required for one disc revolution in each case, by dividing the total seconds by the number of revolutions. The testing constant of the meter was 5/24 watt-hours per disc revolution. If we divide 3600 by the time of one disc revolution, we have the number of revolutions in one hour for that load, and this multiplied by the watt-hour value of one revolution gives the total watts used in one hour, or the total load in watts. This is given in the formula $W = \frac{K \times 3600}{S}$ where *W* is the load in watts; *K* is the testing constant in watt-hours; and *S* is the time of one revolution of the disc.

Slide 556
Testing an A. C. Watt-hour Meter

Using this formula, we computed the watts registered by the watt-hour meter for each load. These values we compared with the average watts shown on the indicating wattmeter. The whole test depends upon the accuracy of this instrument. We obtained the percentage error in each case by dividing the difference between the watts registered by the watt-hour meter and the wattmeter, by the latter reading which is assumed to be cor-

rect. These values were plotted and a curve drawn to show the percentage error or what is practically the same thing, the percentage registration.

Incidentally, the average readings of voltmeter and ammeter were multiplied together, thus finding the load in watts in another way, since the load was non-inductive.

RESULTS:

| Amps. | Volts | Watts Wattmeter | No. of Revolutions Watt-hour Meter | Total Time for All Revolutions |
|---|---|---|---|---|
| . . . | 110.56 | 38.60 | 16 | 5′ 6.6″ |
| 1.13 | 110.1 | 133.47 | 54 | 5′ 4.9″ |
| 2.542 | 110.15 | 279.14 | 113 | 5′ 2.0″ |
| 3.463 | 110.66 | 381.52 | 153 | 5′ 3.2″ |
| 5.053 | 109.44 | 550.09 | 222 | 5′ 2.0″ |

COMPUTATIONS:

| Time of 1 disc revolution | $W = \frac{K \times 3600}{S}$ | Watts = Volts × Amperes. | % Error. |
|---|---|---|---|
| 19.16 Seconds. | 39.1 | . . . . . .* | 1.28% |
| 5.646 " | 132.84 | 124.42 | .48% |
| 2.672 " | 280.68 | 280.02 | .55% |
| 1.981 " | 378.59 | 383.22 | .76% |
| 1.36 " | 551.47 | 553.04 | .20% |

CONCLUSION: The results show that the meter is accurate within the 2 per cent. usually demanded.

(Signed) GLADYS WOOD, ADELAIDE HARTER, EDWARD F. GRUB, HARLOW ANDREWS.

**AN APPLIED METHOD IN METER READING**

In the introduction to his book on the teaching of physics,*[2] Mann asks: "What is the process by which 'physics' and 'daily life' may be brought together?" One method by which his question is answered is given in the following comprehensive contribution, which supplies us with the briefest data and experiment on record.

# THE STUDY OF A METER

BY


## OLIVER C. SHORT

INSTRUCTOR IN CHEMISTRY, TRENTON HIGH SCHOOL, TRENTON, NEW JERSEY


Following you will find a signed exercise required of the pupils of the class in Household Chemistry of the Trenton High School. It is an incidental, but we consider it a very valuable and practical exercise accompanying the study of illuminants, liquid and gaseous, the home appliances, open and closed burners, mantels, etc., and also the study of electricity for heating and lighting.

---

* Ammeter indication was so small that an accurate reading could not be made; and hence the watts could not be computed in the same case.

*[2] "The Teaching of Physics." C. Riborg Mann. The Macmillan Company.

### EXPERIMENT No. 14

## AN EXERCISE IN METER READING

"In class work we study the mechanism of a meter, the marking, reading, and movements of the dials; noting the significance of left to right reading and annexing of ciphers. Then we read our home meters on two successive dates, viz.:

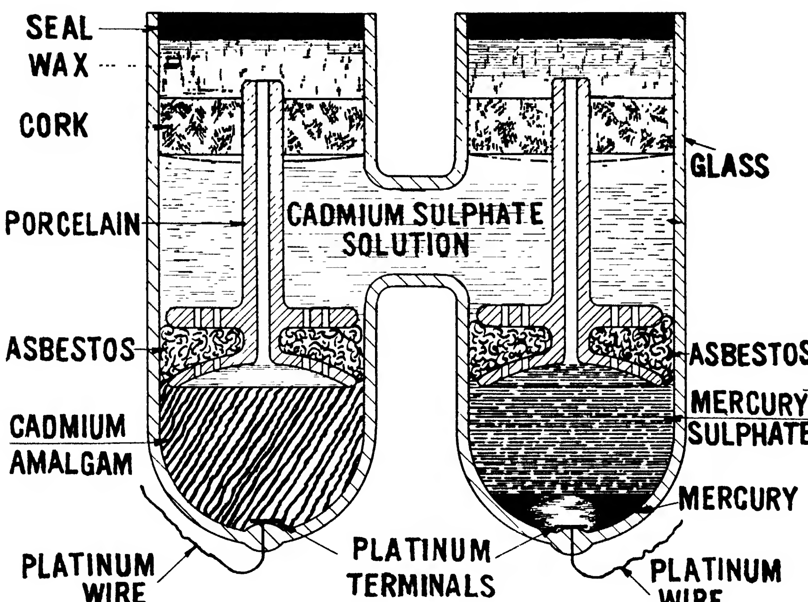
Nov. 20, '14 Reading 50600.
Dec. 10, '14 " 52300.

"The cost of service being nine cents for 100 cu. ft., and noting a difference of 1700, our cost of service for the period was $1.53.

(Signed) "VIVIAN M. BLACKWELL—A[3]
(Signed) "ELLEN O'TOOLE—A[1]"

### EXPERIMENT No. 15

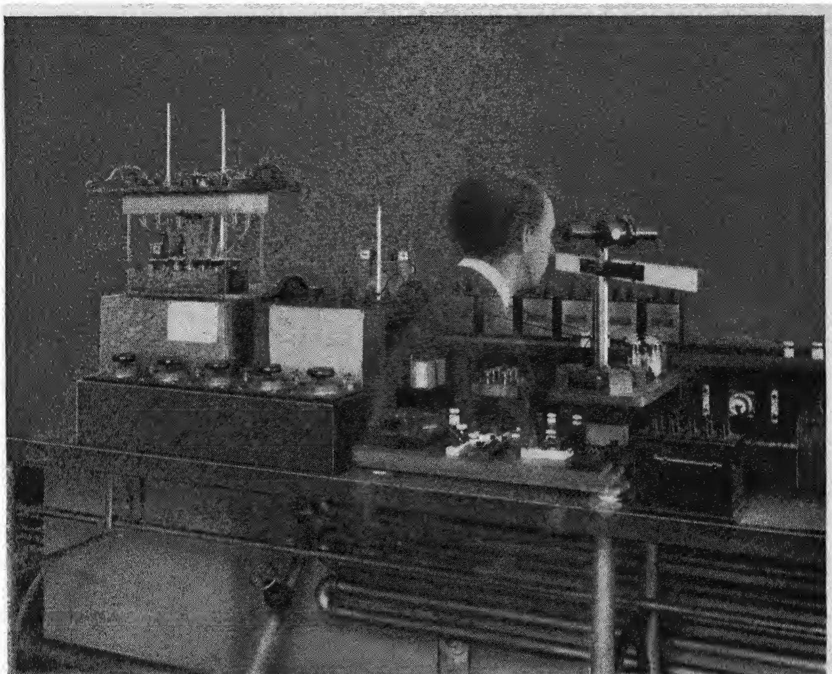
## TESTING WESTON STANDARD AND NORMAL CELLS BY THE OPPOSITION METHOD




Slide No. 557
The Weston Standard Cell

**THE APPARATUS REQUIRED:**

Weston milli-ammeter, 10 milli-amperes.
0.1- to 1.0-ohm resistance standards.
Switch dial box aggregating 100,000 ohms
High-sensitivity reflecting galvanometer.
2 Weston standard cells or normal cells.
2 dry cells.
2 ballast coils, one of approximately 10,000 ohms; the other about 350 ohms.
Commutator.
Circuit-closing switch.
Contact key.



Slide No. 558

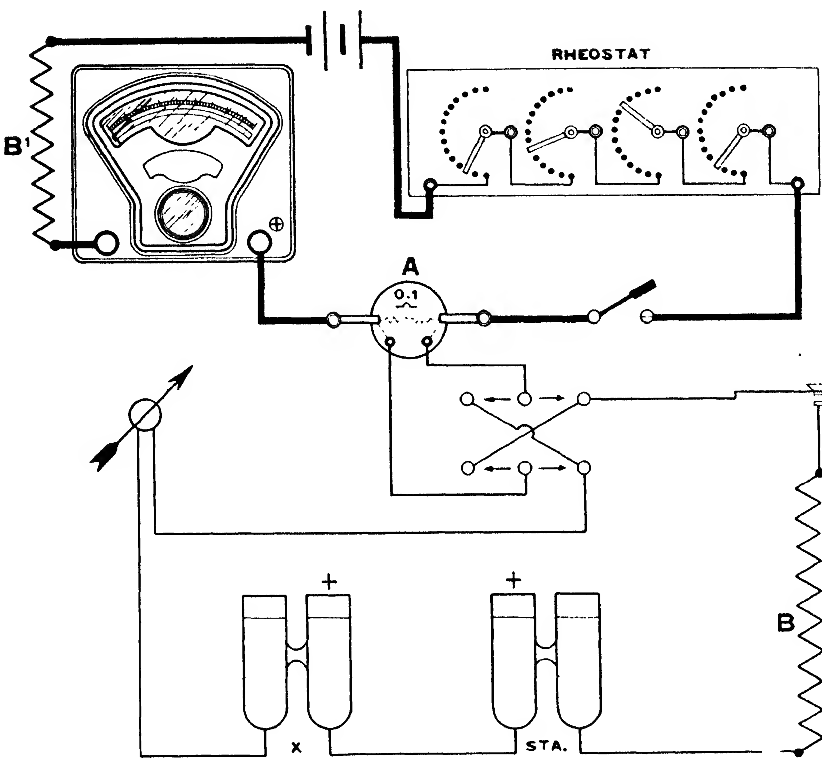
NOTE.—Only those students should be permitted to perform this experiment who are sufficiently advanced to appreciate its remarkable simplicity and accuracy.

This is a zero method and a modification of a more elaborate one used in the Weston research laboratories. It consists in connecting two cells of approximately equal e.m.f. in opposition and determining the difference in e.m.f. between them. When this difference in e.m.f. is not large the results secured by this method far exceed the limit of accuracy obtainable with the highest grade of precision potentiometers.

It is assumed that one of the Weston cells is a certified standard, the e.m.f. of which is known. When connected in opposition to each other (+ to +) they should include in the standard-cell circuit a commutator, a high-resistance ballast coil, a sensitive galvanometer, a circuit-closing key, and the potential terminals of a 0.1-ohm resistance standard. (See Slide No. 559.) The ballast coil, **B**, is useful, as shown, to prevent an excessive current from being passed through the standard cells by accident.

Usually no two cells have exactly the same e.m.f. Therefore, when the standard-cell circuit is closed a current will generally flow, due to the difference in e.m.f. of the two standard cells. This current may be counterbalanced by means of another current from an auxiliary source and reduced to zero. When this is the case no current will flow through the galvanometer. The e.m.f. required to produce the auxiliary current must necessarily be equal to the difference in e.m.f. between the two standard cells.

The auxiliary or regulating circuit includes one or two dry cells, a rheostat, a Weston Model 1 milli-ammeter, the current terminals of a 0.1-ohm resistance standard, a ballast coil, ($\mathbf{B}^1$), and a switch. The ballast coil should be adjusted to permit a full-scale deflection, yet safeguard the milli-ammeter from damage if the rheostat is short-circuited.




Slide No. 559
Testing Weston Standard Cells
by the Opposition Method

The milli-ammeter scale should have 100 divisions; and a full-scale deflection should be obtained with 0.010 ampere.

When a balance is obtained, the indication of the milli-ammeter is noted.

The beautiful simplicity of this method becomes apparent when we realize that besides permitting the comparison of potentials to within 1 part in 100,000, or even 1 part in a million, no calculation whatever is required, the potential difference at the potential terminals of the 0.1-ohm coil being determined directly in microvolts as follows: With full-scale deflection this potential difference ($E = I\ R$) will be: .01 $\times$ 0.1 $=$ 0.001 volt.

The milli-ammeter having 100 divisions, the e.m.f. per scale division will be 0.00001 volt and can, of course, be interpolated to be read to microvolts.

For example, if the e.m.f. of a Weston standard cell is 1.018700, and the direction of the galvanometer deflection indicates that the standard has a higher e.m.f. than X, then the commutator is thrown to the left, whereby the auxiliary current will be in opposition to that of the standard, and if the ammeter pointer stands at 42.6 when balance is secured, then the e.m.f. of X will be 1.018700 — 0.000426 = 1.018274.

Of course, as described, this method is limited to the comparison of cells which do not differ in e.m.f. more than 0.001 volt. When greater differences exist, higher potentials are obtained if a 0.2-, 0.5- or even a 1.0-ohm standard is substituted for the 0.1-ohm standard.

The attention of the student should be called to the fact that an error in reading the scale of the milli-ammeter amounting to an entire division, would introduce an error in his results not exceeding 1/1000% when the 0.1-ohm resistance standard is used; and that if a 1.0-ohm coil is substituted, results may be obtained under the same conditions correct within 1/100%.

Weston standard cells have a temperature coefficient which is negligible in all practical work, but when extreme accuracy is required, the cells should be placed in calorimeters and tested at known temperatures.

An additional double-pole double-throw switch should also be connected so as to permit reversed galvanometer readings, in order to eliminate possible errors due to thermo-currents.

This experiment can be performed by substituting Daniell cells for the Weston cells.

An interesting modification would be to keep one Daniell cell at room temperature and after a preliminary comparison, to raise the temperature of the other cell ten or more degrees, and determine the change in e.m.f. per degree, with both rising and falling temperatures. Instructive results relating to the temperature coefficient and hysteresis of Daniell cells could thereby be obtained.

As already stated, the scope of this method can be extended by using resistance standards of higher values than 0.1 ohm. The same end is attained by substituting a milli-ammeter of greater current range than 0.01 ampere; but in any case, accuracy in the results obtained diminishes proportionately as the milli-ammeter indications represent larger and larger e.m.f. values per scale division.

In checking a Clark cell against a Weston cell, for instance, it would be necessary to balance out the difference between about 1.4340 volts and 1.0187 volts, or 0.4153 volt. To accomplish this, each scale division of the milli-ammeter would have to represent 0.005 volt; and when interpolating to tenths, each estimated sub-division would be equivalent to 0.0005 volt. The attainable accuracy would hence be 5 parts in 14,340, or below 1/30%. Consequently, a potentiometer method would be decidedly preferable.

## CO-OPERATORS

We desire to express our thanks to all physicists, instructors and students who have assisted in the production of this monograph. In particular, we hereby acknowledge our indebtedness to the following co-operators, whose names we list substantially in the order in which their contributions appear.

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